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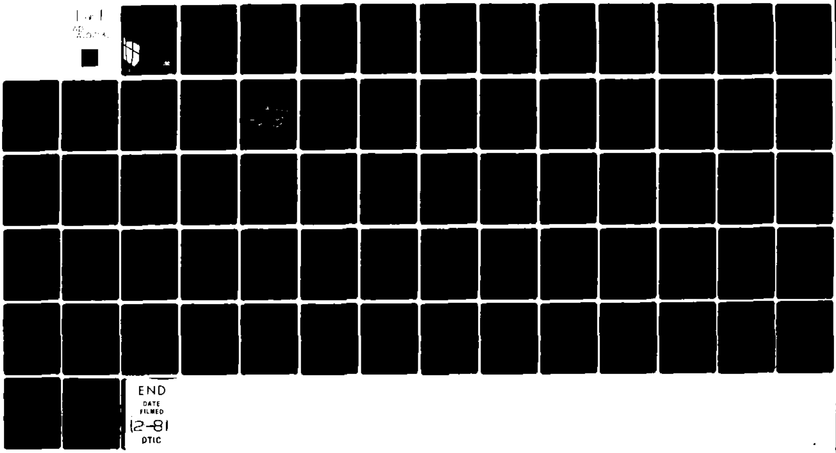

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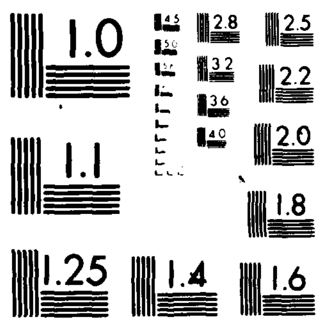

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TECHNICAL REPORT N-108
August 1981

Guidelines for Natural Resources Management and Land Use Compatibility

OVERVIEW OF CONSIDERATIONS IN ASSESSING THE BIOMASS POTENTIAL OF ARMY INSTALLATIONS

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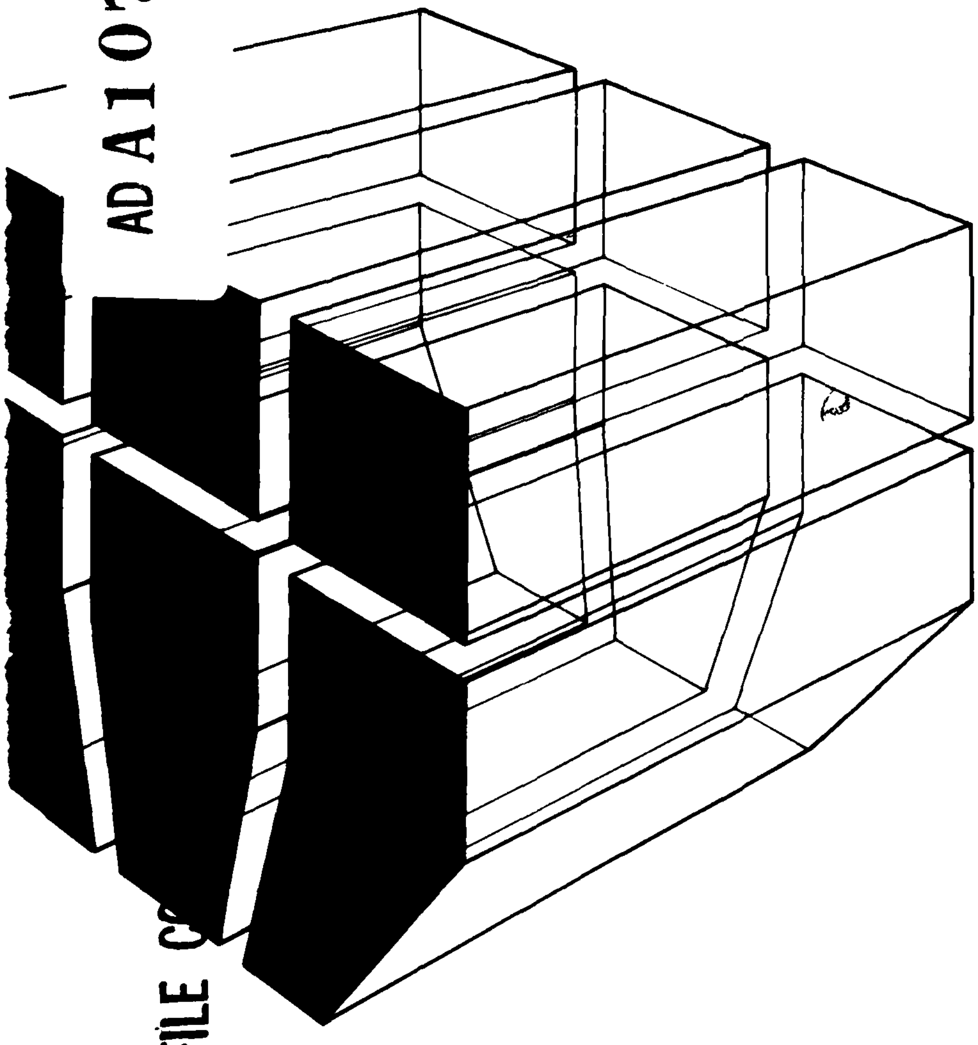

by
R.S. Baran
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This report provides Army installations an overview of necessary considerations for evaluating the feasibility of using forest resources (biomass) as an alternative source of fuel, identifies state-of-the-art land management techniques needed for biomass harvest and management, and provides a comprehensive annotated bibliography on biomass materials. The report focuses on: → cont

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(1) procedures for evaluating biomass availability, (2) techniques of harvesting biomass, (3) the feasibility of military development of energy plantations, (4) the economic feasibility of using biomass, (5) managerial and legal constraints, and (6) ecological and silvicultural implications of biomass use.

FOREWORD

This research was performed by the Environmental Division (EN), U.S. Army Construction Engineering Research Laboratory (CERL) for the Office of the Chief of Engineers (OCE), Directorate of Military Construction, under Project 4A762720A896, "Environmental Quality for Construction and Operation of Military Facilities"; Task B, "Source Reduction, Control, and Treatment"; Work Unit 024, "Guidelines for Natural Resources Management and Land Use Compatibility." The OCE Technical Monitor was Mr. Donald Bandel, DAEN-MPO-B.

Dr. R. K. Jain is Chief of EN. COL L. J. Circeo is Commander and Director of CERL, and Dr. L. R. Shaffer is Technical Director.

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OVERVIEW OF CONSIDERATIONS IN ASSESSING
THE BIOMASS POTENTIAL OF ARMY INSTALLATIONS

1 INTRODUCTION

Background

Because of rapidly rising fuel costs and the strict reductions in fuel oil and natural gas consumption called for by the Army Energy Plan, the Department of the Army (DA) is considering wood fuel as an alternative to petroleum.[1] Wood used for this purpose is one of the "biomass fuels" -- a term which usually refers to any fuel based on a living system, but which has been used to describe energy sources ranging from refuse-derived fuels (RDF) to gasohol. In this report, biomass refers only to living matter derived from silvicultural practices. (A glossary of terms related to biomass is on p 63.) Biomass materials include diseased, lightning damaged, suppressed, crooked, and other undesirable trees, and the tops, limbs, stumps, roots, and other unused portions of individual trees.

Although various harvesting and regeneration techniques have been discussed for years, hard data on the silvicultural, ecological, and economic aspects of this practice are only now becoming available. Private companies have been using whole-tree chipping for the past 10 years, but yield tables are still in the rudimentary stages and sustainable yields have not yet been proven. Institutional barriers such as public law (10 USC 2665[d]) and regulations (Department of Defense [DOD] Instruction 7310.5) exist which could interfere with or prohibit harvesting and regeneration procedures.

The Office of the Chief of Engineers (OCE) has asked the U.S. Army Construction Engineering Research Laboratory (CERL) to examine the feasibility of managing biomass resources for an alternative fuel on installations.

Objective

The overall purpose of this study is to develop means for considering forest resources' potential for use in energy conversion plants. The objectives of the phase of the investigation reported here were: (1) to provide Facility Engineer, OCE, and MACOM personnel preliminary factors to be considered when assessing biomass resources as an alternative source of fuel on Army installations; (2) to identify state-of-the-art technology needed for biomass use, and (3) to provide a comprehensive annotated bibliography on biomass materials.

[1] Army Energy Plan, ADA057987 (Department of the Army [DA], 1978).

Approach

The information in this report was gathered through a literature search to find out what is -- and what needs to be -- known about military use of on-post timber resources for energy production.

Mode of Technology Transfer

Energy production is a new use of installation forest resources. The information in this report may impact on DA Pamphlet 420-7 and Army Regulation (AR) 420-74, which consider traditional uses of military lands.

Steps in Evaluating the Availability of Biomass

Evaluating the potential availability of biomass fuels for installation usage involves five basic steps (Figure 1).

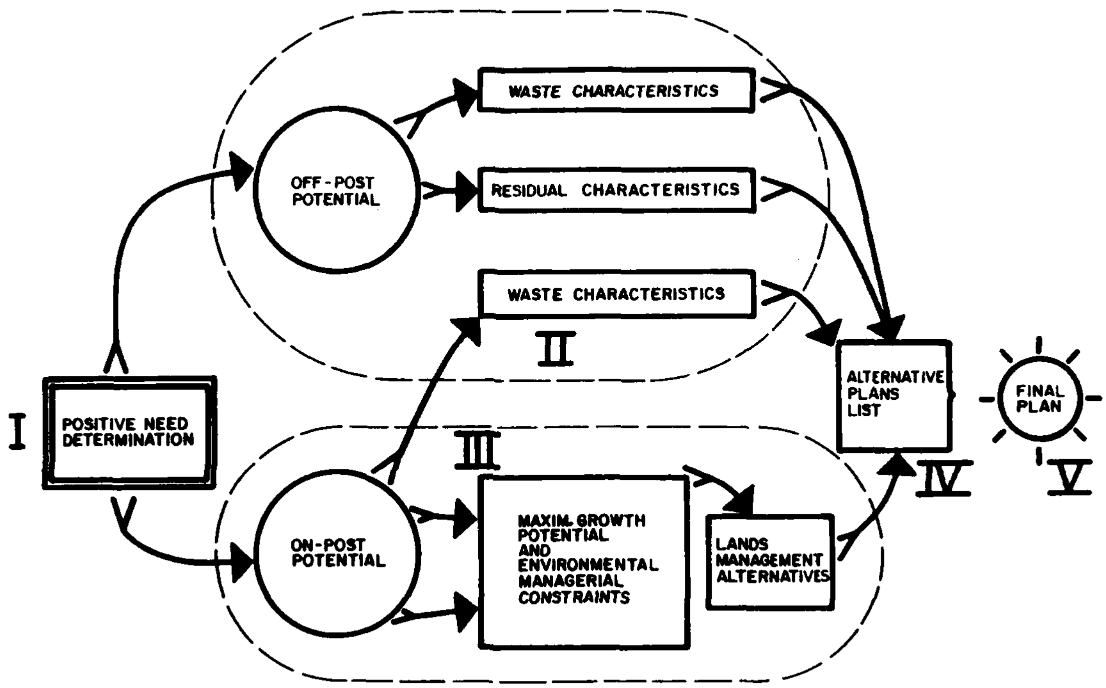

Figure 1. Evaluation procedure.

Step I

Step I is an identification and documentation of the need to replace or convert boilers on the installation. If, as different boiler designs are being considered, wood is identified as a potential fuel source, go to Steps II through V. (This report does not consider alternate boiler designs.)

Step II

Step II is an evaluation of the availability of all wood fuel materials not derived directly from the installation forestry program. This step includes evaluating potential off-post resources such as harvesting

operations, saw mills, furniture manufacturers, and other wood-using industries for waste materials that are, or could be, available on the open market. In addition, use of any on-post waste wood (e.g., pallets, dunnage, crates) should be examined. The goal of this evaluation is to find a stable source of supply.

Step II consists of three distinct parts. Part 1 involves characterizing the waste available from each source. This would require determining the species and form (sawdust, chips, slash, or bark) of the wood. In addition, length of storage, means of storage, and moisture content (e.g., green, kiln dry, air dry) should be considered.

The concern in Part 2 is the total amount of waste available from any given supplier and when it can be obtained. Waste may be available yearly, occasionally, monthly, weekly, or daily depending on the supplier. Included in this part is an evaluation of the variability of supply caused by economic factors such as a decreased demand for certain wood products.

Part III is concerned with cost, including delivery of the biomass to either a storage or use site. This information can be obtained through telephone surveys. The local chamber of commerce and Cooperative Extension Services may be able to help identify sources of waste wood. The results of such a survey must be considered tentative for three reasons. First, waste material is being increasingly used at the point of generation as a source of fuel.[2] Second, utilization standards are becoming increasingly stringent due to new techniques which waste less wood in processing. Finally, new products are being developed to use portions of wood waste and harvested chips for new products (such as flake board) and as a source for chemical production.[3] These developments have caused mill operators to refrain from entering into long-term contracts because a new demand on the supply could cause prices to rise.

Step III

Step III involves evaluating the land base of the installation to check the potential availability of wood fuel on-post. (The sources listed in Appendix A can provide helpful information for the evaluation.) There are three potential sources of land-based fuel on military installations: managed stands (e.g., pine plantations), unmanaged or lesser managed stands (e.g., second-growth hardwood areas or maneuver areas), and energy plantations established by conversion of any of these, or other, areas. Step III will be the most time-consuming and expensive of the five.

2 R. A. Arola, Forest Residue Energy Program, TID-28416 (U.S. Department of Agriculture [USDA], North Central Forest Experiment Station, April 1978), p 297.

3 W. J. Cousins, "Gasification: A Versatile Way of Obtaining Liquid Fuels and Chemicals from Wood," New Zealand Department of Scientific and Industrial Research, Information Service Bulletin 117 (1976), pp 49-53.

For all three types of areas, the biological constraints must be determined. The maximum potential sustainable growth without additional fertilizer or water should be ascertained. This can usually be done by using field survey techniques combined with literature reviews.

While this growth data is being assembled, all environmental or managerial constraints should be identified. Environmental constraints include consideration of rare or endangered species, watershed values, aesthetics, and other associated problems.

Managerial constraints involve a number of issues, most of which can be classified as multiple-use requirements. Foremost among these is the military mission of the installation -- including the uses of specific sites. For example, constraints in a safety zone will be different than in a tracked vehicle maneuver area. Throughout this evaluation, it should be kept in mind that installation sources are interruptable. This has happened during FY80 when harvesting was halted at two installations because of conflicts with rare and endangered species. Any constraints (such as pulpwood and sawtimber production goals) imposed by the forest management plans also must be considered. Wildlife management plans and programs, particularly regarding habitat development, are another potential source of conflict. Legal constraints such as the self-supporting nature of the Army forestry program must also be considered. Lands not being examined for conversion to energy plantations can be evaluated as is typically done for forest management practices, with energy chips being treated as an additional product.

When the evaluation has been completed, alternative land management plans should be developed. The objective of these plans is to maintain a sustainable yield given the biological, environmental, and managerial constraints.

An economic analysis should be done for the various alternatives. If the cost of chips obtained locally and the local cost of stumpage for similar land are known, then the expense of harvest and transport can be estimated by subtracting stumpage from the cost of the chips. Throughout the analysis of alternatives, the installation must make sure that the forestry program does not lose stumpage. In fact, revenues to the forestry program must be increased to cover the additional cost involved in this intensive management. CERL has estimated that the additional effort would require 1 man-month of effort per 1000 acres (404.9 ha) to conduct additional inventory, tree marking, cutting supervision, and harvest contract monitoring.

Step IV

Step IV requires examining all sources of fuel and incorporating these into the alternative plans from Step III to consider various combinations of fiber as fuel.

Step V

Step V consists of adoption and implementation of an alternative plan, including any necessary environmental monitoring.

Energy Plantations

The 19th century European and Asian practice of growing trees on a short rotation for use as fuel wood (energy plantations) was reborn in the United States during the oil problems of the mid 1970s.[4] The purpose of an energy plantation is to produce uniformly fast-growing trees in closely spaced stands, much like corn or wheat. In fact, agriculture is quite often used as a model for what silviculture could achieve.

For biomass production, short-rotation silviculture farms appear to offer several advantages when compared with conventional timber management:[5]

1. Higher yield per unit land area

2. Shorter time span from initial investment to a harvestable crop

3. Uniformity allowing more efficient mechanized operations

4. Regeneration by coppicing reduces regeneration costs.

Disadvantages which must be weighed against the advantages include:

1. High establishment costs

2. Management costs per unit area are generally higher than for conventional forest crops

3. Only sites amenable to mechanized operations may be used

4. Short-rotation farms are usually large monocultures and thus vulnerable to epidemic disease and insect infestation.

Preliminary screening of trees suitable for fast growth and high yield has already been done.[6] Screening criteria were selected to identify trees which will allow maximum use of space and energy. These criteria included:

1. Excurrent growth. Does the tree have one main stem which grows more or less upright?

2. Perennial aboveground stems. Will the tree, once planted, live from season to season?

3. Deciduous. For maximum energy accumulation in temperate climates, deciduous plants are generally more efficient.

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4 D. W. Rose and D. S. DeBell, "Economic Assessment of Intensive Culture of the Short Rotation Hardwood Crops," Journal of Forestry, Vol 76, No. 11 (November 1978), pp 706-711.

5 R. E. Inman, Silvicultural Biomass Farms, Vol 1 (Mitre Corporation, May 1977), 60 pp.

6 C. W. Vail, A Preliminary Screening of Woody Plants as Biomass Crops on Energy Farms (U.S. Department of Energy, December 1979), 36 pp.

4. Narrow compact crown. For close species in these plantations, often less than 1 ft apart, species with a spreading habit are suppressed.

5. Coppicing habit. Will the plant resprout after cuttings without a long dormant period?

6. Rapid juvenile growth. Does the seedling grow rapidly and competitively?

7. Early successional stage. Will the species grow well in poor soils and on harsh, open sites?

Trees that met these standards were then grouped according to their biogeographic requirements. On the basis of climate and geography, candidate biomass crops can be divided into five groups.[7] The groups roughly correspond to five distinct ecoregions of the United States:

1. Pacific Northwest

2. North Central and Northeast

3. South Central United States upland -- drier or better drained sites

4. Transitional zone between regions 3 and 5

5. Wetter sites in the central United States and the entire southern United States.

Habitat characteristics generally dictate the adoption of an energy crop composed of a single tree species. While such uniformity allows easy cultivation and harvesting, there are some biological problems with this approach. Monocultures are vulnerable to substantial losses due to disease and insect infestations. A disease, once established, can quickly infect the entire crop before being recognized or treated; for example, an experimental plot of alder in Georgia was quickly overcome by a fungus.[8]

The main factor influencing the total cost of production is the level of biomass productivity (tons/acre/year). Higher productivity levels result in lower production costs due to shorter transportation distances and greater efficiencies.[9] The major effect of changes in productivity is to alter the number of acres required to produce the needed amount of fuel. Table 1 compares biomass production to the acreage required to fuel a medium-sized boiler plant.

Annual productivity levels of 3 to 4 dry tons/acre (6.7 to 9.0 MT/ha) have been achieved by using intensive cultivation methods on experimental

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[7] C. W. Vail.

[8] K. Steinbeck and C. L. Brown, Increasing the Biomass Production of Short Rotation Hardwood Coppice Forests (University of Georgia, March 1979), p 19.

[9] D. W. Rose and D. S. DeBell, "Economic Assessment of Intensive Culture of the Short Rotation Hardwood Crops," Journal of Forestry, Vol 76, No. 11 (November 1978), pp 706-711.

Table 1

Sustained-Yield Productivity Versus Land Needs

Dry Tons/Acre/ Year Yield (MT/ha)	Acreage Required (ha)	Square Miles (km^2) Required
1 (2.24)	1.2×10^5 (4.9×10^4)	187.5 (485.6)
5 (11.20)	2.3×10^4 (9.3×10^3)	35.9 (93.0)
10 (22.39)	1.2×10^4 (6.9×10^3)	18.8 (48.7)
15 (33.59)	7.7×10^3 (3.12×10^3)	12.0 (31.1)
20 (44.78)	5.8×10^3 (2.35×10^3)	9.1 (23.4)
25 (55.98)	4.6×10^3 (1.86×10^3)	7.2 (18.7)

Assuming: 120 million Btu boiler plant
65 percent boiler efficiency
60 percent boiler load
15 million Btu/dry ton

plots of American sycamore in Georgia.[10] Theoretical values approaching 20 dry tons/acre/year (48 MT/ha) have been estimated, but such yields are far from being reached in practice.

Dense timber stands envisioned for silvicultural biomass farms prohibit the use of existing equipment for cultivation and harvest. Machines similar to those used in agriculture cultivation and harvest systems have been proposed but not yet developed.[11]

This overview of the energy plantation concept reveals that major problems still must be solved. Large areas of land are needed to meet fuel requirements of even modestly sized boiler or power plants. Scarcity of required acreage dictates unrealistically high timber-stand density, and annual growth that can be achieved only with intense cultivation practices which will add to the already high initial costs (Table 2).[12] Finally, these operations require the efficiency afforded by highly mechanized systems, but the equipment has not advanced beyond the theoretical stage.

[10] K. Steinbeck, "Short-Rotation Forestry in the United States: A Review," American Institute of Chemical Engineers (AICHE) Symposium Series, Vol 70, No. 139 (1974), pp 62-66.

[11] R. S. Evans, Energy Plantations: Should We Grow Trees for Power Plant Fuel (Vancouver, B.C.: Western Forest Products Lab, July 1974), p 23.

[12] K. Howlett and A. Gamache, Silvicultural Biomass Farms, Vol II, "The Biomass Potential of Short-Rotation Farms," Technical Report 7347 (Mitre Corporation, May 1977), p 162.

Table 2

Typical Annual Costs for Short-Rotation
Biomass Production
(From K. Howlett and A. Gamache, Silvicultural Biomass Farms;
Vol II, "The Biomass Potential of Short Rotation Farms,"
Technical Report 7347 [Mitre Corporation, May 1977], Table 5-5.)

Practice	Cost per Dollars per Acre (ha)
Monoculture Maintenance	
Competition Control:	
Mowing	4-6 (9.9 - 14.8)
Cultivation	4-15 (9.9 - 37.0)
Herbicides	4-18 (9.9 - 44.44)
Herbicide Application:	
Terrestrial	4-6 (9.9 - 14.8)
Aerial	5-7 (12.35 - 17.28)
Fertilization	
Fertilizer:	
Nitrogen	8-99 (19.75 - 244.44)
Phosphorus	10-35 (24.69 - 86.42)
Potassium	4-10 (9.9 - 24.69)
Application:	
Terrestrial	1-10 (2.57 - 24.69)
Aerial	5-7 (12.35 - 17.28)
Protection	
Fire Control:	
Firebreak maintenance and patrols 1 (2.57)	
Insect, disease, and animal control 4-5 (9.9 - 12.35)	
Irrigation	
System Installation	100-670 (246.91 - 1654.32)
Operation and Maintenance	20-50 (49.38 - 123.46)

Harvesting Considerations

A harvesting method using commercially available equipment is a primary requirement because (1) harvesting on military lands is done by contract, and (2) most existing forestry programs are understaffed and underfunded.[13] The system also needs to be able either to selectively thin or clear cut areas to assist in the military training mission, wildlife management, rare and endangered species management, and other areas of natural resources management.

CERL examined four alternative harvesting methods: a system to bale residue, a topwood harvesting system, a machine to harvest, chip, and transport residues in a single operation, and a whole-tree chipping system.

The University of Virginia is developing a system to bale already collected residue to facilitate transport and storage.[14] The residue is allowed to field dry, then it is baled and transported to the site of use. The bales are then processed on-site into either pellets or chips.

In a cooperative venture, the U.S. Forest Service, Department of Energy, Boise Southern Company, Georgia Pacific Corporation, International Paper Company, OlinKraft, Inc., Weyerhauser, and Nicholson Manufacturing, and in a different project (Swedish) are developing machines to harvest, chip, and transport chips in one operation. However, the prototype machines chip only small-diameter trees, the operating cost is high, and none of the machines is commercially available.[15]

The U.S. Department of Agriculture (USDA) Forest Service's North Central Forest Experiment Station is developing a topwood harvester to be used primarily in hardwood stands after a conventional harvest has been completed.[16] The machine will gather the residual tops, severing and aligning large limbs to facilitate skidding the tops out without damaging the stand. This machine is still in the prototype stage.

Whole-tree chipping is now being used commercially in the United States.[17] This system (Figure 2) is based on the use of a whole-tree chipper which is designed to produce chips from trees up to 24 in. (609.6 mm) in diameter outside bark. Chipping is done in the field and is usually supported by a seven-man crew (not including truck drivers). The basic operation involves

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[13] Report on the Review of the DOD Forestry Program, No. 800-085 (Defense Audit Service, Systems and Logistics Audit Division, April 2, 1980), p 1.

[14] Forest Products Research Society Conference, Exposition (February 1980).

[15] P. Koch and D. W. McKenzie, "Machine to Harvest Slash, Brush, and Thinnings for Fuel and Fiber -- A Concept," Journal of Forestry (December 1976), pp 809-812; Gustaff Siren, "Silviculture for Bio-Energy in Sweden," Proceedings: Bio-Energy 80 (April 1980); W. S. Fuller, "Technology to Achieve an Energy/Fiber Balance," Proceedings: Bio-Energy '80 (April 21-24, 1980), pp 302-304; P. Koch and T. E. Savage, "Development of the Swathe-Felling Mobile Chipper, Journal of Forestry (January 1980), pp 17-21.

[16] R. A. Arola, Forest Residue Energy Program, TID-28416 (USDA Forest Service, North Central Forest Experiment Station, April 1978), p 300.

[17] Paul M. Butts and D. N. Preston, "Whole Tree Chipping... A Forest Management Tool," Georgia Forest Research Paper #4 (June 1979).

two feller-bunchers which are used to fell and deck the trees. Two skidders then move the trees to the chipper where any usable sawlogs are bucked off and decked separately. A boom is then used to feed the tree into the chipper with the chips being blown into two different vans, one for pulp quality chips and the other for lower quality chips which could be used for energy. This system is capital-intensive: estimates of initial equipment costs are as high as $700,000. For the system to run efficiently, skilled operators are needed, thus increasing labor costs. These investment and labor costs make high levels of production necessary; successful commercial operations on the average produce 50,000 tons (45 454.5 MT) a year.[18] The remainder of this chapter will deal with aspects of whole-tree chipping exclusively.

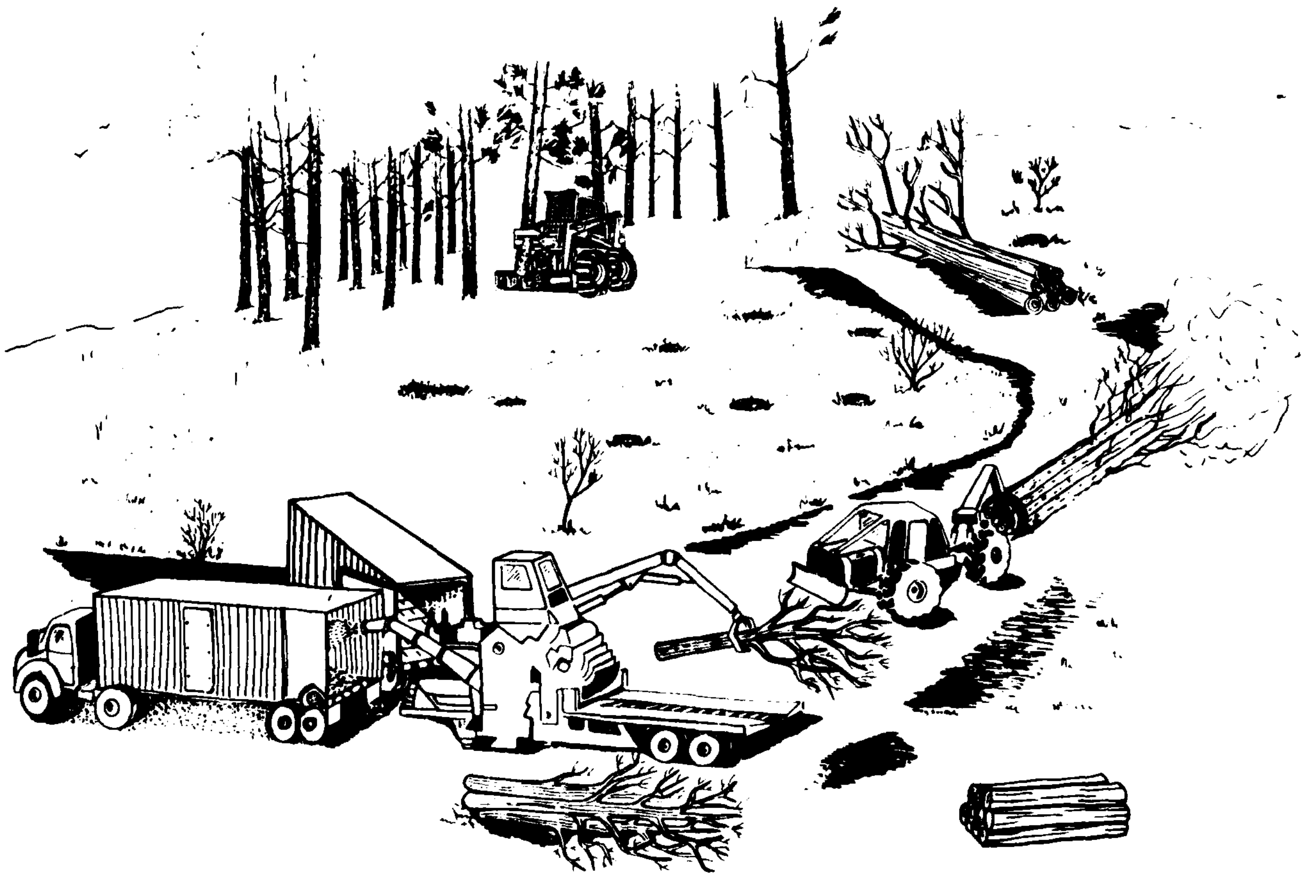

Figure 2. Schematic for whole-tree harvest system.

[18] I. S. Goldstein, D. L. Holley, and E. L. Deal, "Economic Aspects of Low Grade Hardwood Utilization," Forest Products Journal, Vol 28, No. 8 (1978), pp 53-56.

Silvicultural Implications

Whole-tree chipping is increasing throughout the United States on private, commercial, and Government (including DOD) lands.[19] In fact, the development of the whole-tree chipper was more in response to increasing timber utilization than to the current energy situation. Flake board, for instance, can be made of timber that was previously considered unmerchantable.[20] As the current standing crop is increasingly used, both beneficial and detrimental effects are expected.

Some positive effects of removing harvest residues have been known to foresters for many years. Whole-tree chipping reduces the quantities of harvest residue (slash), which in turn: (1) lessens the frequency of fire, (2) reduces the need of fire control methods such as controlled burns, and (3) makes site preparation easier.[21] Whole-tree chipping both allows second-growth, low-quality material to be cleared out because the chips produced are merchantable, and makes it more economical to thin lightning-damaged, diseased, suppressed, and undesirable species. In addition, stumpage increases in response to market demand for low-quality chips and the "aesthetic" value of the stand is increased.[22]

The negative effect most often thought to occur with whole-tree chipping is loss of soil nutrients due to the removal of organic material (harvest residue).[23] However, there are objections to this theory. The entire issue of nutrient loss is quite controversial; this report discusses the best information now available. Some researchers feel that the use of most of the aboveground tree growth on sites with good soils will have little effect on long-term productivity.[24] The highest concentration of recyclable nutrients is found in the leaves and small twigs. With whole-tree use techniques, only a single year's leaf crop is removed, and much of that crop is left because of equipment operation.[25] Many of the small twigs, leaves, and leaf fragments are rejected from the chipper. A secondary source is mechanical handling before chipping. On soils that have low, easily depleted nutrient levels, whole-tree utilization is not recommended.[26]

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[19] P. Paul, "Wood Chips for Fuel," Soil Conservation (September 1978), pp 16-17.

[20] R. A. Arola, Fiber for Structural Flakeboard... Mechanized Thinning and Topwood Recovery (USDA Forest Service, North Central Forest Experiment Station), p 6.

[21] L. Burkholder, "Abundunt and Low Cost Wood Fiber Through Maximum Forest Utilization," Proceedings: Bio-Energy '80 (April 1980) pp 53-56.

[22] L. Burkholder, "Whole Tree Chipping Provides an Answer to Multiple Wood Fiber Use," Pulp and Paper (June 1978), p 4.

[23] A. L. Leaf, Proceedings: Impact of Intensive Harvesting on Forest Nutrient Cycling (State University of New York, School of Forestry, 1979).

[24] MORBARK Industries, Total Chiparvestors (MORBARK International Brouchure); Personal communication with William Darwin, USDA Forest Service, Atlanta, GA; Personal communication with John W. Mixon, Chief Forest Research, Georgia Forestry Commission.

[25] Leaf, Proceedings.

[26] Personal Communications with Jack Hornick, USDA Forest Service; H. E. Young, "Forest Biomass as a Source of Energy: A Policy Statement for New England," Report No. 1, The Northern Logger (October 1979).

Forest mensuration practices are only now beginning to include whole-tree techniques[27] with studies concentrating on northern hardwoods,[28] northern softwoods,[29] or stands in the southeast. Most of these studies measure only total weight. Merchantable bole or pulpwood sticks are seldom accounted for, and many studies report components of the tree as a percentage of either the bole or the entire tree, excluding stump and roots. Table 3 (with information converted to percentages to aid comparison) presents the results of several studies in southern pine stands. It is assumed that 1000 board feet (2.36 m^3) of scaled timber represents 200 cu ft (5.66 m^3) of actual tree and 80 cu ft (2.26 m^3) per cord.[30] These estimates are lower than other figures used for U.S. military installations[31] because they are based on northern hardwood stands.[32] It is not possible to apply a single figure to all installations because of the variation in climate, physiography, history of the stand, species type, stocking level, local managerial or environment constraints (military mission, presence of rare and endangered species), and market conditions. Richard Welch, Resource Analyst of the USDA Forest Service, Southeast Forest Experiment Stand, has developed a table to calculate from a standard timber survey the volume of residue available after commercial harvest.[33] This table was designed for use on southern pine plantations but may help in estimating on-post resources.

Ecological Implications

The effects of whole-tree utilization may be more significant on an ecological rather than a silvicultural basis, but such discussions are difficult due to site specificity. Removing diseased, lightning-damaged, suppressed and undesirable trees means that much wildlife habitat will be lost.[34] Soil nutrient losses are a potential problem, as discussed in Silvicultural Implications (p16). The extent of these effects will vary both with the faunal species involved and with the ultimate reforestation method used.

Cuts will have effects that vary with the extent of the thinning. It can be anticipated that the loss of the trees will mean a loss of habitat for a

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[27] J. P. McClure, N. D. Cost, and H. A. Knight, Multisource Inventories -- A New Concept for Forest Survey, SE-191 (USDA Forest Service, 1979), p 68.

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[30] R. D. Byram, H. M. Van Bavel, and J. P. Van Buigtenen, "Biomass Production of East Texas Woodlands," Technical Association of the Pulp and Paper Industry (TAPPI), Vol 61, No. 6 (June 1978), pp 65-67.

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Table 3

Comparison of Available Residues

Source	Branches	Tops	Foliage	Crown	Slash
Keays, J. L., 1978[a] Percent of the unbarked full bole all softwoods	15	5	10	25	30
Clark, M. A., III, 1978[b] Percent of main stem barked (6 in.-18 ft. diameter at breast height [dbh]) Southern pines in natural stands	17		Needles 5	22	
Clark, M. A., III, 1978[b] Proportion of total tree unbarked (6 in.-18 in. dbh) Southern pines in natural stands	14		4		
Byram, R. D., 1978[c] Percent of merchantable bole unbarked (6 in.-18 in. dbh) N.E. Texas softwoods	15		5		
Welsh, R. L, 1978[d] Percent of total merchantable volume Southern softwood				13	
Beltz, R. C., 1976[e] Softwood saw-log residue Percent residue per merchantable volume					12/11

a J. L. Keays, "Complete-Tree Utilization of Mature Trees," American Institute of Chemical Engineers, Vol 70, No. 139 (1974), pp. 67-76.

b A. Clark, III, "Total Tree and Its Utilization in the Southern United States," Forest Products Journal, Vol 28, No. 10 (October 1978), pp 47-52.

c R. D. Byram, H. M. Van Bavel, and J. P. Van Buijtenen, "Biomass Production of East Texas Woodlands," TAPPI, Vol 61, No. 6 (June 1978), pp 65-67.

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e R. C. Beltz, Comparison of Harvested Volume to Inventory Volumes in Midsouth Logging Operations, Thesis, Louisiana State University (1976).

number of plant and animal species. The species involved will depend on which tree species are lost, the age profile of those trees, and other factors such as canopy closure. Loss in diversity will be one of the most important results of thinning. Some nongame species will benefit from a thinning operation, as would many game species such as deer. The primary difference between the effects of "normal" thinning and of thinning using whole-tree chipping operations is the amount of residue left in the stand. The detrimental ecological effects can be lessened if critical mast-producing trees and den trees are not cut. Clearcuts using whole-tree chipping differ only in slash disposal, but unlike conventional clearcuts, there will be no slash piles left as cover.

Economics

Whole-tree chipping is a capital-intensive venture requiring skilled equipment operators and equipment which may cost $700,000 just for the equipment that has to be used in the forest. This does not include costs for handling, storage, or preparation of the wood at the boiler site.[35] For a description of equipment and equipment mix, see Harvesting Considerations, (p 14).

An average commercial operation will produce approximately 50,000 tons (45 454.5 MT) of chips per year. An output of this magnitude is necessary to support the high equipment costs and skilled operators needed to run the equipment.[36]

Representative examples of the delivered cost of chips are $11 to 12.50/ton (Weyerhauser test, 1976),[37] $13/ton,[38] and $18 to $23/ton.[39] The wide range in cost is due to the differences in years (1976 versus 1980), in the grades of chips (hardwood versus softwood), and in the amount of transportation required. Because there are more potential products in areas where whole-tree utilization is practiced, stumpage has increased and stands considered to have an inoperable volume have been used and rejuvenated more effectively.[40] But if, on a military installation, the low-quality chips from harvest operations are delivered directly to on-post boiler plants, the forestry program will lose not only this initial gain in stumpage, but also some of

[35] I. S. Goldstein, D. L. Holley, and E. L. Deal, "Economic Aspects of Low Grade Hardwood Utilization," Forest Products Journal, Vol 28, No. 8 (1978), pp 53-56.

[36] P. Paul, "Wood Chips for Fuel," Soil Conservation (September 1978), pp 16-17; Personal communication with Earl L. Deal, Extension Forest Resources Specialist (Harvesting), North Carolina State Agricultural Extension Service; R. L. Schnell, "Whole Tree Chipping in the Tennessee Valley," Southern Lumberman (September 1, 1978), pp 13-15.

[37] R. L. Schnell, pp 13-15.

[38] Personal communication with William Darwin, USDA Forest Service, Atlanta, GA.

[39] Personal communication with Robert Carrington, District Forester, District One, Texas Forest Service.

[40] N. N. Quinney, "Economics of Utilizing Residuals From Logging -- Problems and Opportunities," AICHE Symposium Series, Vol 71, No. 146 (1975), pp 30-33; MORBARK Industries, Total Chiparvestors (MORBARK International Brochure).

the stumpage from the original timber. This is critically important because military forestry operations are funded through the timber sales program, and unless a way is developed for the utility budget to legally reimburse the forestry fund for the lost stumpage, the Army will not be able to economically justify using this system.

Energy Implications

Whole-tree chips are being used in boilers, in the wood products industry, and elsewhere.[41] Like other fuels, wood's composition varies; therefore, a fuel characterization must be done for each installation. Much of the variation is caused by differences in both species mix and age class structure. The younger the tree, the greater the bark-to-heartwood ratio and the greater the proportion of twigs and foliage. Seasonal differences caused by leaf fall and movement of sap must also be accounted for in energy calculations. Data from the USDA Forest Service illustrate the range of Btu values among species.[42] The low stemwood, oven-dry, heartwood value is 8000 Btu/lb (17 660 kJ/kg) for a white fir, compared with 12,230 Btu/lb (26 998 kJ/kg) for pitch pine, which is considered a high value. This difference is caused by the variability in wood density: the lower the density, the lower the Btu value.[43] Figure 3 shows that as the moisture content increases, the Btus per pound decrease. Generally, wood is assumed to have an oven-dry moisture content of 8500 Btu/lb (19 720 kJ/kg). If it then is assumed that whole-tree chips have 50 percent moisture content, and if 1 Btu (1.05 kJ) is required to remove 1 lb (0.453 kg) of the water, then: (8500 Btu [19 720 kJ/kg]/1.0-0.12)(0.50) equals 4830 Btu/lb (11 205 kJ/kg) of wood. (To perform more detailed calculations, see Appendix B.) This is only an estimate of the as-received value of whole-tree chips; the range of Btu values for individual species, varying moisture content, varying species and age composition, and varying growth form (open growth versus plantation) are not accounted for.

Use of wood fuel reduces the need for some major air pollution control equipment. Since wood contains only negligible amounts of sulfur, SO_X emissions do not have to be controlled.[44] Air pollution control problems do occur because of an increase in particulate emissions, but these are much easier to control than SO_X emissions.

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[41] L. H. Blackerby, "Sierra Sawmill Eliminates $380,000 Annual Oil Bill With Hog-Fuel Boiler," Forest Industries (August 1974), pp 70-71.

[42] P. J. Ince, How to Estimate Recoverable Heat Energy in Wood or Bark Fuels, General Technical Report FPL-29 (USDA Forest Service, Forest Products Laboratory, 1979), p 99.

[43] B. Russell, The Feasibility of Generating Steam in West Alabama Using Wood as a Fuel (West Alabama Planning and Development Council, September 1976), p 75.

[44] I. S. Goldstein, D. L. Holley, and E. L. Deal, "Economic Aspects of Low Grade Hardwood Utilization," Forest Products Journal, Vol 28, No. 8 (1978), pp 53-56.

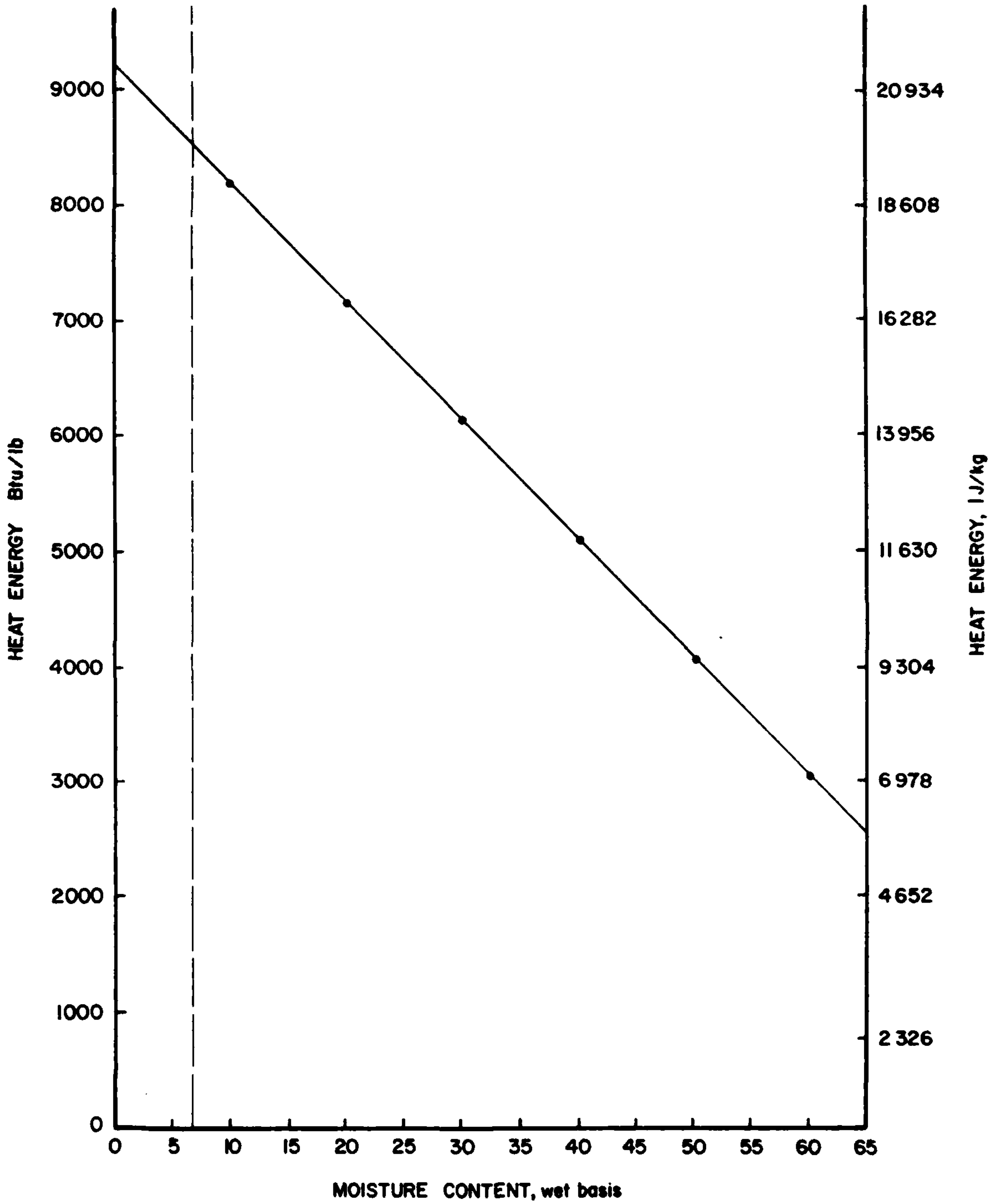

Figure 3. Heat energy versus moisture content.

Wood fuel is cheaper than most fuels at current prices on a million Btu (MMBtu) received basis. Figure 4 illustrates the number of MMBtus per dollar for various fuels at varying costs. The wood fuel is treated as received at a 50 percent moisture content. The cost per MMBtu on the horizontal axis is compared with the cost per unit on the vertical axis. Costs are figured on an as-received basis. No attempt has been made to account for boiler efficiencies. For example, at $3.00/MMBtu ($2.54/GJ), fuel oil would cost between $0.04 and $0.05/gal ($0.011 and $0.013/L); wood fuel, wet-weight basis $21/ton ($23.15/MT); air dry, $38/ton ($41.90/MT); oven-dry $44/ton ($45.51/MT); coal $4/ton ($4.41/MT); and natural gas $3/1000 cu ft ($0.11/m^3). If the installation is paying $0.05/gal ($0.013/L) for #2 fuel oil, it could pay slightly more for #6 fuel oil; $22/ton ($22.05/MT), wood fuel wet weight, $32/ton ($35.28/MT), wood fuel air dry; $52/ton ($57.33/MT) wood dry; $3.50/1000 cu ft (($0.13/m^3), natural gas; or $95/ton ($104.74 MT) for coal for the equivalent MMBtus.

Managerial Constraints

Timber growth and removal serves multiple purposes on most installations. Forests are needed on-post primarily so that troops can practice a wide range of military tactics and maneuvers. Forested areas also serve other purposes, such as timber production, wildlife management, recreation, watershed protection, and rare and endangered species management. These uses can hinder the development of an area exclusively for energy production. However, whole-tree

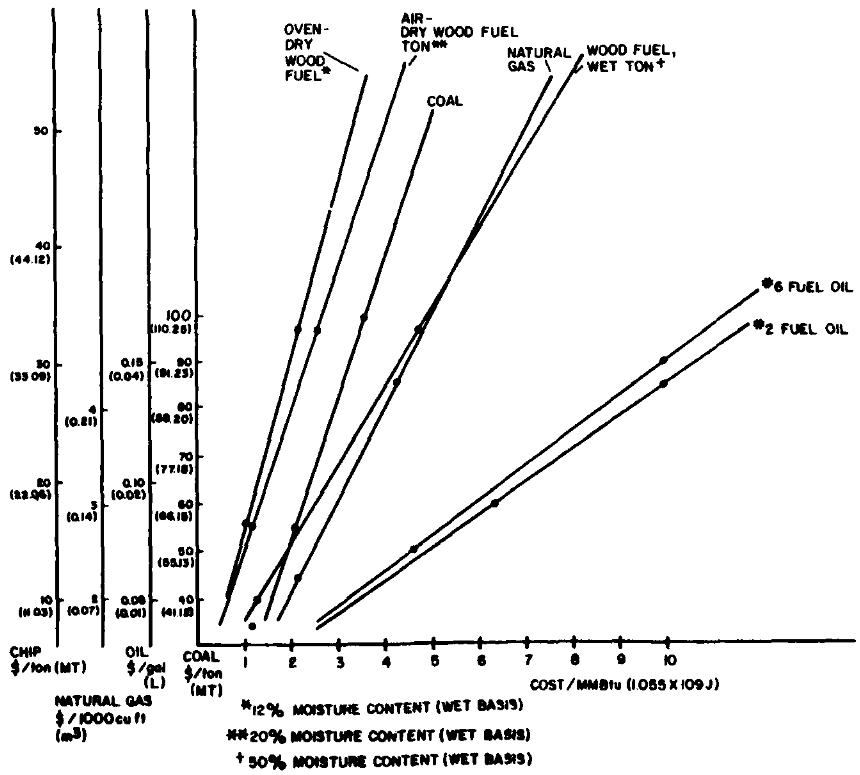

Figure 4. Alternative fuel cost per MMBtu comparison.

chipping, properly applied, can help solve this problem, and at the same time provide energy chips for wood/coal boilers. This technique allows the thinning of trees necessary to obtain the desired effect while minimizing damage to the residual stand. In addition, whole-tree chipping could prove to be an effective test for land-sharing operations.

Another constraint is the loss to the forestry program of stumpage. If previously commercially productive acreage is converted to energy production, all potential future stumpage generated by that acreage will be lost. Local harvesting operations and primary consumers may also be hurt by the loss of this resource. First, whole-tree chipping operations will require more work from installation foresters and will cause a manpower drain on the forestry section. Second, delivering chips harvested on military lands to the installation's boilers will cause a decrease in stumpage received by the forestry section. This is the result of the harvester subtracting the cost of the chips from the stumpage paid for the rights to harvest and remove the portions (generally the bole and large limbs) that are salable in the local market. Stumpage rates are determined by many variables, including type of wood, amount of merchantable timber, terrain, weather, and market conditions. Therefore, it is impossible to indicate how much stumpage will be affected. It is clear, however, that loss of stumpage and increased manpower costs will occur.

Potential Legal Constraints

The laws and regulations under which Army forestry programs are conducted do not allow total flexibility in the use of forest resources. The typical installation operations and maintenance (O&M) budget does not pay for forest management expenses. Rather, in accordance with DOD Instruction 7310.5, expenses directly related to the production of economically valuable timber are expected to be paid for through sales -- in the current year -- of that timber. Expenditures are limited to anticipated proceeds on a year-by-year basis (DOD Instruction 7310.5, paragraph E), with the excess proceeds, if any, returned to the U.S. Treasury's general fund. An installation could enter into a contract to supply fuel to a wood-burning power plant off-post, but the payments could be used only for forestry program expense (DAEN-CCZ memo dated 7 May 80, J. Steelman), and could not reduce in any direct way the cost of purchased utilities.

Other types of harvest are more readily accepted. The slash and other residue left after completion of a normal harvest contract is certainly "abandoned," with ownership reverting to the installation. This may be picked up, chipped, and burned in the heating plants, but the cost of reharvested wood is very large compared with other sources of biomass fuel. Culls, downed trees, and other "noncommercial" stems may be harvested for energy purposes in much the same manner that they are now sold locally for firewood. Should this use reduce the availability of fire wood to local users, though, the existing policy commitment must be re-examined. There is also a possible conflict with the authorization statute (10 USC 2665[d]) if "significant" forestry program effort is expended in managing for these "noncommercial" trees.

The most easily defensible pattern for on-post consumption might follow these steps:

1. On-post timber is advertised and sold for use as energy chips.

2. Contractor bids and pays the forestry program an amount based on anticipated costs as compared to open-market value.

3. Installation utilities section purchases these or other chips on the open market.

The competitive bid and resulting sales contract might also require that a certain proportion of the chips harvested be made available for buy-back at a guaranteed price.

Clearly, the purchase of materials on the open market will always be the most acceptable approach and will be open to the least criticism. This may not be practical where there is a market of high demand and low supply; in such a case, the guaranteed buy-back must be used. In other areas, large quantities of wood wastes are readily available for purchase at low prices. In these regions, there is probably little reason for on-post resources to be diverted to energy use, so many questions will not arise.

The limitations of the forestry program and its separation from the installation O&M budget create several practical problems when use of on-post forest resources for installation energy needs is considered. The transition of the harvested chips through the open market is now the most easily supported alternative.

3 CONCLUSIONS

1. This report has provided preliminary guidance for investigating the use of installation forest resources for energy. The report has included: (a) an evaluation of alternative wood materials, (b) an initial examination of energy plantations' potential, (c) an examination of harvesting equipment and techniques, (d) an initial assessment of potential silvicultural and ecological implications, and (e) an identification of managerial and legal restrictions.

2. Some gaps in technology may make biomass use economically impractical. Specifically, equipment for harvesting biomass is expensive.

3. Legal constraints concerning the use of timber resources managed by the military appear to favor purchase of the material through the open market. This will allow the individual products from each tree to return its highest value to the Government through use as a traditional forest product, sawlogs, pulp chips or cost reduction in fuel of residue used as energy chips.

4. Since biomass is a new area of concern, the annotated bibilography in Appendix A will be useful to Army installations needing more information about management of timber resources for this fuel.

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APPENDIX A:

ANNOTATED BIBLIOGRAPHY

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Boyle, J. R. and A. R. Ek, "An Evaluation of Some Effects of Bole and Branch Pulpwood Harvesting on Site Macronutrients," Canadian Journal of Forest Research, Vol 2 (1972), pp 407-412. Evaluates macronutrient removals by conventional and "bole and branch" harvest in a mixed hardwoods stand in north central Wisconsin. Soil reserves of N, P, and Mg are 5 to 15 times greater than the amounts removed by a harvest at the end of a 45-year rotation; K and Ca reserves are 1 to 3 times greater than the amounts removed. Natural inputs of nutrients are estimated to supplement these reserves over such rotations.

Boyle, J. R., J. J. Phillips, and A. R. Ek, "Whole Tree Harvesting: Nutrient Budget Evaluation," Journal of Forestry (1971), pp 760-762. Evaluates the N, P, K, and Ca budgets of 30 acres of second growth 40-year-old aspen-mixed hardwood in Lincoln County, WI. Nutrient accumulation was calculated based on the bulk density for the whole soil; input via precipitation was calculated from existing information. Calcium reserves appear to be potentially limiting, but only after the tenth 30-year rotational harvest.

Brown, J. K., J. A. Kendall Snell, and D. L. Bunnel, Handbook for Predicting Slash Weight of Western Conifers, General Technical Report INT-37 (USDA Forest Service, International Forest and Range Experiment Station, 1977), 35 pp. An aid to manage fuel and woody debris. Describes procedures for predicting slash weight using table values relating either slash weight per tree by dbh, or slash weight per square foot of tree basal area by dbh.

Burkholder, L., "Whole-tree Chipping Provides an Answer to Multiple Wood Fiber Use," Pulp and Paper (June 1978), p 4. Praises whole-tree chipping because of its versatility. A chip harvester can produce pulp grade chips or fuel chips using branches and cull trees.

Butts, P. M. and D. N. Preston, "Whole-Tree Chipping -- A Forest Management Tool," Georgia Forest Research Paper (June 4, 1979), p 8. Lists the advantages and disadvantages of whole-tree chipping. Concludes that the volume from chipping can be increased 1-1/2 to 2 times over conventional logging, which makes this method practical for many stands of timber.

Byram, R. D., C. H. M. van Bavel, and J. P. van Buijtenen, "Biomass Production of East Texas Woodlands," TAPPI, Vol 61, No. 6 (June 1978), pp 65-67. A whole-tree inventory of East Texas pineywoods based on Forest Service survey data. Includes component weight to bole weight ratios for varying dbh classes, and annual increment data.

Carlisle, A., The Utilization of Forest Biomass and Forest Industry Wastes for the Production and Conservation of Energy, 1976 (Petawawa Forest Experiment Station, Chalk River, Ontario, 1976), 54 pp. This report covers various topics, including central electric power production fueled by wood, home heating, and conversion to liquid gaseous fuels. The report concludes that although the use of forest products for fueling large, central power plants is unfeasible, wood can provide mill energy and might produce liquid fuels economically.

Carpenter, E. M., Secondary Wood Residue: Production, Use and Potential in the Twin City Area, Research Paper NC-144 (USDA North Central Forest Experiment Station, St. Paul, MN, 1977), 6 pp. Presents volume, characteristics, disposal, and uses for wood residues from secondary wood manufacturing plants in Minneapolis-St. Paul, MN.

Chemicals From Wood Waste (performed by R. Katzen Associates for USDA Forest Service, Madison, WI, December 14, 1975), 50 pp. Provides a diagram of the various extractive and synthetic processes used to produce chemicals from wood.

Choong, E. T. and D. L. Cassens, "Fuel Values, Moisture Content, and Density of Fresh and Piled Louisiana Hardwood Sawmill Residues," Louisiana State University Wood Utilization Notes, Note No. 31 (October 1976), p 4. Tables list the caloric content, moisture content, and density of sawdust and bark generated by a Louisiana sawmill.

Clark III, A., "Sawmill Residue Yields from Yellow-Poplar Saw Logs," Forest Products Journal, Vol 26, No. 1 (January 1976), pp 23-27. Describes a study to develop prediction equations and yield tables for estimating the weight of lumber, bark residue, chippable residue, and sawdust produced from yellow-poplar sawlogs. Sawlogs produced averages of 54 percent lumber, 45 percent bark, 18 percent chippable residue, and 13 percent sawdust.

Clark III, A., "Suggested Procedures for Measuring Tree Biomass and Reporting Tree Prediction Equations," *Forest Resource Inventories: Workshop Proceedings*, Ft. Collins, CO, *Vol. II (Colorado State University, July 23 to 26, 1979)*, pp 615-628. Examines different field methods and measurements for developing tree weight equations. Includes tables relating linear associations among stem weight, total tree weight, and crown weight, and various tree dimensions (e.g., dbh, total height) for several southern species. Also suggests a consistent method for recording data and equations which includes species and location of stand, tree dimensions measures, and the model and equations developed.

Clark, A., "Total Tree and Its Utilization in the Southern United States," *Forest Products Journal*, Vol 28, No. 10 (October 1978), pp 47-61. Using summaries of data abstracted from other studies, the author developed equations to predict the dry weight of wood and bark in the main stem and crown for red oak, yellow poplar, and the four major species of southern pine. The equations show -- for the various harvesting methods -- what proportion of wood and bark is left as logging residue.

Clark III, A., D. R. Phillips, and H. C. Hitchcock III, *Predicting Weights and Volumes of Southern Red Oak Trees on the Highland Rim in Tennessee*, Research Paper SE-208 (USDA Forest Service, Southeastern Forest Experiment Station, 1980), 23 pp. Total aboveground biomass was determined for 29 trees 5 to 22 in. dbh. The average tree contained 70 percent of its green weight in stem material to a 4-in. top and 30 percent in crown material. Equations are presented for predicting green and dry weight and green volume of the total tree and its components using dbh, total height, height to a 4-in. top, and sawlog merchantable height (separately or in combination). These equations were used to develop tables showing weight and volume of the total tree and its components by dbh and total height class.

Clark III, A., and J. G. Schroeder, *Biomass of Yellow-Poplar Natural Stands in Western North Carolina*, Research Paper SE-165 (USDA Forest Service, Southeast Forest Experiment Station, 1977), 41 pp. Trees 6 to 28 in. dbh were sampled to determine aboveground biomass. The average tree's total dry weight was composed of 91 percent stem material and 9 percent branch material. Specific gravity, moisture content, and green weight per cubic feet data are presented for the total tree and its components. Regression equations were used to develop tables which show weight and volume of the total tree and its components using dbh and total height class.

Clark III, A. and M. A. Taras, *Biomass Shortleaf Pine in a Natural Sawtimber Stand in Northern Mississippi*, Research Paper No. SE-146 (USDA Forest Service, Southeast Forest Experiment Station, 1976), 32 pp. Shortleaf pine trees 6 to 20 in. dbh from a natural sawtimber stand in northern Mississippi were sampled to determine weight and volume of aboveground biomass. The average tree from a total of 34 trees has 88 percent of its wood in the stem and 12 percent in the crown. Tables predict weight and volume of the total tree and its components by dbh and total weight classes.

Clark III, A., and M. A. Taras, "Comparison of Aboveground Biomasses of the Four Major Southern Pines," Forest Products Journal, Vol 26, No. 10 (October 1976), pp 25-29. Compares the aboveground biomass of four major species of southern pine 6 to 20 in. dbh growing in natural uneven-age sawtimber stands. Biomass of the four differed significantly; on the average, sampled trees had 83 percent of their dry weight in wood, 13 percent in bark, and 4 percent in needles.

Clark III, A., and M. A. Tara, "Effect of Harvesting to Various Merchantable Limits on Loblolly Pine Logging Residue,"Forest Products Journal, Vol 24, No. 6 (June 1974), pp 45-48. Biomass prediction equations were developed from a stratified sample of 35 loblolly pine sawtimber trees. These equations are used to estimate the composition and dry weight of logging residue remaining after an unevenly aged loblolly stand is harvested to variously sized merchantable tops. Logging to a 6-in. dib results in 526 lb dry residue per ton of wood and bark logged compared to 200 lb per ton when logging to a 2-in. top.

Clark III, A. and M. A. Tara, Slash Pine Sawtimber Stem Weights and Sawmill Residue Yields, Research Paper SE-122 (USDA Forest Service, Southeastern Forest Experiment Station, March 1975), 14 pp. Forty-three slash pine trees 10 to 21 in. dbh were sampled in southern Alabama. Each sample was felled, limbed, and bucked into sawlogs and pulp wood. After processing of a sawmill, weight data were used for prediction equations which estimate primary product weight, stem weight with and without bark, green weight of chippable residue, bark residue, and sawdust.

Clark III, A., M. A. Taras, and J. G. Schroeder, Predicting Green Lumber and Residue Yields From the Merchantable Stem of Yellow-Poplar, Research Paper SE-119 (USDA Forest Service, Southeastern Forest Experiment Station, 1974), 15 pp. A stratified random sample of 47 yellow-poplar sawtimber trees 11 to 28 in. dbh was selected from a mature unevenly aged stand in western North Carolina. About 1 percent of main weight was in material 4 to 2 dib, 10 percent in pulp wood, and 89 percent in sawlogs. Equations were computed to predict lumber and residue yields.

Cole, D. W. and P. Gessel, "Movement of Elements Through a Forest Soil as Influenced by Tree Removal and Fertilizer Additions," Proceedings: North American Forest Soils Conference (1963), pp 95-104. Four one-tenth acre plots located on the Cedar River watershed in northeast Washington were selected for treatment and study. One plot was clearcut, while the other two plots received nitrogen fertilizer at the rate of 200 lb per acre. One plot received ammonium sulfate $[(NH_4)_2SO_4]$; the other plot received urea. Extensive elemental leaching 10 months after treatment did not occur in this soil-flora system. Only 65 percent of the nitrogen from the urea application passed through the forest soil, while 88 percent of the nitrogen from the ammonium sulfate was lost. Concludes that limiting anion addition by fertilization will limit the leaching of cations.

Conner, R. N., and C. S. Adkisson, "Effects of Clearcutting on the Diversity of Breeding Birds," Journal of Forestry (December 1975), pp 781-785. Observes that the diversity of breeding bird species and the number of birds are initially reduced in a clearcut area and on a 1-year-old pole stand. However, both species diversity and number of birds greatly increased in the 3-, 7-, and 12-year-old clearcuts. Concludes that a clearcutting program which leaves dead snags and some live trees standing, and does not disc or burn slash, will have the net effect of increasing the numbers of birds and bird species.

Cousins, W. J., Gasification: A Versatile Way of Obtaining Liquid Fuels and Chemicals from Wood (New Zealand Department of Scientific Industrial Research, 1976), pp 49-53. Describes pyrolysis and gasification of wood, especially the effect heating conditions exert in determining which of the 200 possible products will be obtained.

Craft, E. P., Utilizing Hardwood Logging Residue: A Case Study in the Appalachians, Research Note NE-230 (USDA Northwestern Forest Experiment Station, Upper Darby, PA, 1976), 7 pp. A clearcut hardwood stand in Appalachia was evaluated to determine (1) the total weight of residue on the study area after commercial harvest of merchantable sawlogs, and (2) the amount of residue suitable for sawing into marketable products.

Cunningham, C., "Logging Trucks for -77," Canadian Forest Industries, Vol 97, No. 4 (April 1977), p 4. Describes several major developments in trucks and trucking that may have an important effect on logging operations: e.g., better engines, tires, greater mileage and less downtime. A listing and short description of major logging trucks on the market is also included.

Currier, R. A., Manufacturing Densified Wood and Bark Fuels, Special Report 490 (Oregon State University Extension Service, January 1978), 4 pp. Describes three types of wood briquettes: fuel logs, stoker fuel, and fuel pellets. A list of known present manufacturers of wood and bark residue densification machines is appended to this leaflet.

Currier, R. A., D. P. Dykstra, R. D. McMahon, and S. E. Corder, Potential Energy Uses for Diseased and Beetle-Killed Timber and Forest Residues in the Blue Mountain Area of Oregon, DOE Report No. RLO/2227-T33-1 (Forest Research Laboratory, Oregon State University, September 1978), 58 pp. Presents a "road map" to solve two problems: (1) the means to use 1.5 million acres of dead or dying lodgepole pine, and (2) use of logging residues. These problems are divided into four broad topics: availability of raw material, harvesting and transportation, methods of utilizing the material for energy, and feasibility analyses. Each topic area produced recommendations for needed research.

Curtis, A. B., Fuel Value Calculator (USDA Forest Service Information Center, 1979), 2 pp. Allows one to compare the price of fuel presently used to that of other fuels, based upon equivalent heat values. Chips, sawdust, and bark values are given for various moisture contents.

Curtis, A. B., Jr., "Wood for Energy: An Overview," Forest Products Utilization Bulletin (USDA Forest Service, September 1978), p 4. A brief explanation of how and why energy (from wood) could help alleviate this nation's energy crisis.

Demeter, J. J., C. P. McCann, J. M. Ekmann, and D. Bienstock, Combustion and Emissions Study of Char and Oil From Pyrolyzed Wood Waste (Pittsburgh Energy Research Center, June 1978), 26 pp. The combustion and handling characteristics of char produced by pyrolysis of wood waste were determined in a 500 lb/hr pulverized-coal-fired test facility and as slurry with No. 6 oil in a 100-hp, oil-fired boiler.

DiNovo, S. T., W. E. Ballantyne, L. M. Curran, W. C. Baytos, K. M. Duke, R. W. Cornaby, M. C. Matthews, R. A. Ewing, and B. W. Vigon, Preliminary Environmental Assessment of Biomass Conversion to Synthetic Fuels, EPA-70077-78-204 (Battelle Columbus Laboratories, October 1978), 366 pp. Presents a preliminary evaluation of biomass production and conversion technologies. Of five categories detailed, agricultural and forestry wastes, and urban and industrial wastes have the most immediate potential for significant energy contributions. Details are given concerning biochemical and thermochemical conversion processes. Also includes six brief scenarios of commercial scale plants processing appropriate regionalized feedstock.

Dunwoody, J. E., Resolving the Environmental Issues in Developing Fuels From Biomass (Mittlehauser Corporation), 14 pp. Reviews recent studies on the potential environmental impact by biomass energy technologies, then outlines a framework for a national program of biomass energy environmental research. The need for a substantial biomass energy environmental research program is emphasized to prevent environmental concerns from inhibiting the commercial application of biomass energy technologies.

Dyer, R. F., Fresh and Dry Weight, Nutrient Elements and Pulping Characteristics of Northern White Cedar, Technical Bulletin 27 (University of Maine at Orono, August 1967), 40 pp. Studies were completed in two phases, based on tree size: (1) sampling of 21 commercial-sized trees, and (2) sampling of 36 trees ranging in height from 1 to 35 ft. Tables relate the weight and nutrient information.

Ellis, T. H., "Should Wood be a Source of Commercial Power?" Forest Products Journal, Vol 25, No. 10 (October 1975), pp 13-16. A feasibility analysis considering resource availability, the general cost of power production, and the applicability of energy plantations.

Energy and Chemicals From Forests (USDA Forest Service, Forest Products Laboratory, 1978), 12 pp. Presents some ideas on how the forest can help solve the United States' energy problems; direct combustion of residues is merely one way of using forest fiber more fully to conserve energy. Current research is highlighted.

Energy from the Forest (ENFOR) Review, Vol 1, No. 1 (Canadian Forestry Service, March 1980), p 70. Reviews a number of projects sponsored by the Energy From the Forest (ENFOR) program. This program of the Canadian Forestry Service has two segments: Biomass conversion and biomass

production. Copies of the detailed reports may be obtained using addresses supplied with individual project descriptions.

Energy From Forest Biomass on Vancouver Island (prepared by Paul H. Jones and Associates, Ltd., for the Canadian Forestry Service, 1979), 67 pp. Determines the availability and cost of forest biomass on Vancouver Island for energy production. Relates total annual availability of logging slash and material from precommercial thinnings. Cost of removal ranged from $73.50/cut unit (cunit) to a low of $25.10/cunit within a road hauling distance of 30 to 40 mi.

Environmental Readiness Document: Biomass Energy Systems, DOE/ERA-0021 (Department of Energy, Assistant Secretary of Environment, September 1979), 48 pp. Evaluates the commercial readiness of biomass energy system technology with respect to environmental issues. Outlines major environmental and socioeconomic concerns which may delay the application of biomass energy technologies. Among these concerns are large land and water requirements, soil erosion, soil fertility reduction, and harmful pollutants. Also lists pertinent regulatory impact on biomass systems.

Erickson, J. R., *The Moisture Content and Specific Gravity of the Bark and Wood of Northern Pulpwood Species*, Research Note NC-141 (North Central Forest Experiment Station, St. Paul, MN, 1972), 3 pp. This paper presents the moisture content and specific gravities for wood chips and bark from the bole and tree tops of six northern hardwood species. The specific gravity is computed three ways: (1) Dry weight over green volume, (2) Dry weight over dry volume, (3) Green weight over green volume.

Esser, M. H., ed., *Proceedings: Lightwood Research Coordinating Council, Annual Meeting* (January 18-19, 1977), 193 pp. Technical discussion of various chemical manipulations designed either to improve tree health or enhance the extraction of chemicals.

Evans, R. S., *Energy Plantations: Should We Grow Trees for Power Plant Use*, Report No. VP-X-129 (Canadian Forestry Service, July 1974), 23 pp. A review of biomass literature suggests that energy plantations are not practical in most regions of North America, except for the Pacific Northwest. Areas from 240 to 1000 sq mi would be required to sustain a 150-MW power plant. Data from the Pacific Northwest suggests 65 sq mi of red alder might support a 150-MW plant.

Factsheet: DOE Biomass Energy Program (Conservation and Solar Energy, Department of Energy), 4 pp. A variety of techniques for converting the many forms of biomass into energy are briefly discussed: pyrolysis, fermentation/distillation, and combustion.

Faurot, J. L., *Estimating Merchantable Volume and Stem Residue Volume in Four Northwest Timber Species: Ponderosa Pine, Lodgepole Pine, Western Larch, Douglas Fir*, Research Paper INT-196 (USDA Forest Service, Intermountain Forest and Range Experiment Station, Ogden, Utah, 1977), 55 pp. Presents tables and equations for estimating total cubic volumes of wood, wood

residue, and bark for four species of trees. Tables represent second-growth trees 80 years old or less, ranging in size from 1-1/2 in. dbh to the maximum diameter measured for the respective species.

Feasibility of Utilizing Forest Residues for Energy and Chemicals, Contract No. NSF-AER-75-19464 (USDA Forest Service, March 1976), 193 pp. Included are current energy usage by industry, requirements for and the availability of residue, research on process alternatives to meet energy and/or chemical requirements, and economic and technical feasibility analyses.

Forest Biomass Studies, "Section 25: Yield and Growth" (International Union of Forest Research Organizations, University of Maine at Orono, March 1971), p 240. Papers concerning total forest biomass, distribution, component biomass, and methods for sampling the above.

"Forest Product Residuals," American Institute of Chemical Engineers Symposium Series, Vol 71, No. 146 (W. K. Lautner, editor, 1975), 66 pp. Although not site-specific, the articles in this collection describe forest product residuals starting from their generation in the field, through economics, methods of removal, and final use as energy.

Forest Residues Energy Program, TID-28416 (North Central Forest Experiment Station, St. Paul, MN, April 1978), 297 pp. The objective of this study was to determine (1) the energy needs of the pulp and paper mills of specific regions, and (2) the extent to which "wood residues" can meet those needs. Four key questions are addressed in the report: (1) how much wood is potentially harvestable for wood fiber and energy, (2) what is the cost of delivery, (3) what are the mills' energy requirements, current sources of energy, and potential for converting to wood fuel, and (4) at what prices can wood fuel compete with other energy sources?

Fortin, J. A., R. Lavallee, and Y. Piche, Forest Utilization for Energy and the Role of Nitrogen Fixation: A Literature Review, Project P-9 (Canadian Forestry Service, October 1979), 166 pp. Outlines the basic mechanisms of nitrogran fixation and summarizes available information on using forests for energy. The role of nitrogen and other nutrients is examined as intensive forestry techniques are implemented to meet increasing demands for fiber. Soil fertility is the focus of research strategies concerning the positive effects of nitrogen-fixing bacteria as a means to minimize the use of fertilizers.

Frisque, G., Volume of Wood Residues for Energy Production at Parent: Summary, ENFOR Project P-6 (Laurentian Forest Research Centre, November 1979), 15 pp. Results of a study to determine the quantity and quality of available wood residues to supply fuel for a proposed thermal electric plant. An average of 57.3 tons of fresh residues per hectare found after three-length logging of jack pine and an average of 393.3 kg of residue chips per cubic meter of piled wood in a sawmill's yard are sufficient to supply a 3-MW thermal plant which would meet the needs of the sawmill and an adjacent town.

Furman, L. H. and L. G. Desmon, "Wood Residue for Veneer Drying -- A Case History," Forest Products Journal, Vol 26, No. 9 (September 1976), pp 52-55. Propane was replaced with wood residue as a fuel for two veneer dryers;

after a year of operation the use of propane was reduced by more than 1.6 million gal/yr, and almost $500,000 per year in fuel costs was saved if residues are considered to have no value.

Gardner, R. B., "Pipeline Chip Transportation," from Proceedings: Rocky Mountain Forest Industries Conference (1976), pp 179-186. Continuing research on the transportation of wood chips via pipeline may have significant application in the forest products industry.

Gardner, R. B., Skyline Logging Productivity Under Alternative Harvesting Prescriptions and Levels of Utilization in Larch-Fir Stands, INT-247 (USDA Forest Service, Intermountain Forest and Range Experiment Station, June 1980), 35 pp. Studies the economic and environmental feasibility of harvesting timber at more intensive levels on steep terrain. Four levels of wood utilization from conventional sawlog to almost total fiber recovery were applied under each of three silvicultural techniques -- shelterwood, group selection, and clearcut harvesting. The highest production in total cubic feet of fiber removed occurred with group selection and running skyline yarding downhill. The most important variables affecting rate of production were yarding distance, lateral yarding distance to skyline, and number of pieces per turn.

Gardner, R. B. and D. W. Hann, Utilization of Lodgepole Logging Residues in Wyoming Increases Fiber Yield, Research Note INT-160 (Intermountain Forest and Range Experiment Station, Ogden, Utah, April 1972), 6 pp. "Near-complete harvesting" entails chipping material that would be left as residue following a "conventional harvest." Near-complete and conventional harvests are compared, with an emphasis on the volumes of fiber harvested with each process.

Gikis, B. J., Preliminary Environmental Assessment of Energy Conversion Processes for Agricultural and Forest Product Residue, Vol I (Stanford Research Institute, March 1978), 181 pp. A preliminary assessment of the environmental impacts of conversion processes which produce energy or fuel from forest and agricultural residue. Conversion processes considered are gasification-pyrolysis, liquefaction-pyrolysis, combustion, and anaerobic digestion. Fifteen examples represent combinations of agricultural residues and conversion processes available in various geographical locations.

Goldstein, I. S., D. L. Holley, and E. L. Deal, "Economic Aspects of Low-Grade Hardwood Utilization," Forest Products Journal, Vol 28, No. 8 (August 1978), pp 53-56. Low-grade hardwoods are residual trees after a harvest of either high-graded hardwoods or pine plantations, and are unsuitable for use in the forest products inventory. The cost of this low-grade material delivered to a central location is $20/dry ton. This material cost is compared to the potential value returned by producing energy, chemicals, or fiber board. The potential availability on a specific site in North Carolina Piedmont is described.

Gorham International, Inc., An Assessment of the Technical and Economic Feasibility of Converting Wood Residues to Liquid and Gaseous Fuel Products Using State-of-the-Art and Advanced Coal Conversion Technology (Gorham International, Inc., January 1979), 10 pp. Attempts to determine which

state-of-the-art and advanced coal gasifiers are technically and economically suitable for wood residue gasification, and to specify various modifications necessary to convert these gasifiers for efficient use with wood residues.

Graham, R. T. and Jonalea R. Tonn, Case Study: Growth and Development of Forest Stands in the Northern Rocky Mountains, INT-255 (USDA Forest Service, Intermountain Forest and Range Experiment Station, August 1980), 23 pp. Thirty-six stands on 11 forests were sampled using permanent plots in 1970 and 1971 and again in 1975 and 1976. These thinned stands and stands scheduled for thinning were selected in order to strengthen the data base used in forest planning for northern Rocky Mountain habitat types. Tree diameter and growth were highly variable among habitat types. Ten-year growth also varied.

Graham, R. T. and Jonalea R. Tonn, Response of Grand Fir, Western Hemlock, Western White Pine, Western Larch, and Douglas Fir to Nitrogen Fertilizer in Northern Idaho, INT-270 (USDA Forest Service, Intermountain Forest and Range Experiment Station, September 1979), 8 pp. Young coniferous forests were studied to determine their response to nitrogen fertilizer. Height growth means showed significant differences between fertilized and unfertilized stands. When each species was analyzed separately, only Grand Fir and Douglas Fir showed a significant response to fertilizer application.

Guha, S. R. D. and P. C. Pant, "Chemical Pulps for Writing and Printing Papers from Ailanthus Excelsa Roxb.," Indian Forester, Vol 87, No. 4 (1961), pp 262-265. Describes laboratory experiments on the production of chemical pulps from Ailanthus excelsa using the sulphate process to provide suitable papers for writing and printing.

Hamilton, D. A., Jr., "Setting Precision for Resource Inventories: The Manager and the Mensuration," Journal of Forestry, Vol 77, No. 10 (October 1979), pp 667-670. Uses a hypothetical inventory contract to describe all the elements needed to determine "optimal" precision. These elements are (1) a loss incurred if the estimate is in error, (2) a cost to conduct the inventory, and (3) a defined population to be sampled. Describes the responsibilities of both the mensurationist and manager, emphasizing the manager's role.

Hann, D. W. and J. D. Brodie, Even Aged Management: Basic Managerial Questions and Available or Potential Techniques for Answering Them, INT-83 (USDA Forest Service, Intermountain Forest and Range Experiment Station, September 1980), 30 pp. Presents traditional forest even-aged management aims to optimize decision-making by partitioning planning into separate decisions dealing with optimal planting density, thinning plan, rotation length, fertilization, and species mix. This report advances the practice of linear programming to aid in forest planning. Discusses the advantages of such programs and cites extant computer systems can be used in decision-making.

Harder, M. L. and D. W. Einspahr, "Bark Fuel Value of Important Pulpwood Species," TAPPI, Vol 59, No. 12 (December 1976), p 132. Lists the specific gravity, density, and Btu value of bark from 24 pulpwood species.

Hirsch, S. N., G. F. Meyer, and D. L. Radloff, Choosing an Activity Fuel Treatment for Southwest Ponderosa Pine, RM-67 (USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, November 1979), 15 pp. Discusses fuel appraisal methods and results obtained from a case study addressing the problem "What fuel treatment will have the greatest net benefit?" Projections using fuel bed, fire behavior, and probability modeling indicate that when only timber-related cash flows are considered, piling and burning slash is preferred. This treatment also has the highest expected annual burned acreage.

Hiser, M. L., ed., Wood Energy, Proceedings of Governor William G. Milliken's Conference (Michigan Public Service Commission, November 29, 1977), 152 pp. Articles collected during a conference held to shed light on wood as an alternative source of energy. Speakers included engineers, public officials, foresters, academics, and plant managers.

Hog-Fuel Availability in British Columbia (by Reid, Collins and Associates, Ltd., for British Columbia Wood-Waste Energy Coordinating Committee, May 1978), 78 pp. Presents volume data on production and surpluses of hog fuel for British Columbia in 1976, the 1980s, and early 2000s. The best possibilities for the co-generation of steam and power are in regions characterized by significant hog fuel surpluses concentrated at specific centers.

Hog-Fuel Co-Generation Study: Quesnel, British Columbia (H. A. Simons [International], Ltd., British Columbia Wood-Waste Energy Coordinating Committee, May 1978), 60 pp. Based on a yearly hog-fuel surplus of 350,000 units, a preliminary plant design was completed which used this fuel to generate electric power. Electrical-generation costs developed show a range of 13.2 to 17.3 mills per kWh, costs competitive with the British Columbia Hydro and Power Authority.

Hollings, B. C. and Ferner, Ltd. and G. C. Scott, Forest Industries Energy Research Summary, Report No. 12 (New Zealand Energy Research and Development Committee, University of Auckland, Private Bag, Auckland, New Zealand, October 1976), 38 pp. Presents a scheme for a comprehensive study of biomass, including its growth, generation as industrial residue, availability, and conversion processes.

Host, J. and J. Schlieter, Low-Cost Harvesting Systems for Intensive Utilization in Smallstem Lodgepole Pine Stands, Research Paper INT-201 (USDA Forest Service, Intermountain Forest and Range Experiment Station, 1978), 20 pp. Three different skidding methods -- small rubber-tired skidder, horse, and small-tracked tractor -- were evaluated in an overmature lodgepole pine stand in Montana. Skidding production, product volume removed per acre, and residue volume per acre are compared for each of five similar cutting units. On a capital investment basis, horse skidding is the most efficient.

Houghton, J. E. and L. R. Johnson, "Wood for Energy," Forest Products Journal, Vol 26, No. 4 (April 1976) pp 15-18. States that assuming the current demand for other used products, residues could supply between 1/10 and 4/10 of 1 percent of the United States' energy needs. Supported by calculations using general Forest Service inventory data on a basic conversion factor.

Howlett, K. and A. Gamache, "The Biomass Potential of Short Rotation Farms," Silvicultural Biomass Farms, Vol II, Report No. 7347 (Mitre Corporation, May 1977), 135 pp. The management of short-rotation silvicultural biomass farms is compared with that of current timber stand management. Three species which are the most promising candidates for short-rotation farming are identified for various areas of the United States. Management practices are evaluated for productivity versus costs.

Howlett, K. and A. Gamache, "Forest Mill Residues as Potential Sources of Biomass," Silvicultural Biomass Farms, Vol VI, Technical Report No. 7347 (Mitre Corporation, May 1977), 124 pp. Identifies the major sources of forest and mill residues, estimates current availability, cost and utilization, then predicts future availability. Characteristics of the residues which are pertinent to their usefulness as an energy source are described.

Hudson, W. D. and K. Kittleson, Identification of Wood Energy Resources in Central Michigan (Michigan State University, Remote Sensing Project, November 1978), 37 pp. Information on the location and quality of forested acreage in Michigan was collected using aerial photography and satellite imagery data; this information was then compared to known sample plot data to assess accuracy.

Hupa, M., K. H. Karlsson, and B. Strifuaras, "Deposit Formation in Boilers With Combined Firing of Fuel Oil and Bark," Paperi Ja Puu, Vol 58, No. 11 (1976). Samples of fireside deposits from 13 industrial boilers using either fuel oil or bark or both were analyzed. These data and the rate of deposit growth are discussed in terms of the ratio between input of basic and acidic oxides with the fuel, and compared with the amounts of specific substances fed into the boiler.

Hyde, P. E. and S. E. Corder, "Transportation Costs in Oregon for Wood and Bark Residues," Forest Products Journal, Vol 21, No. 10 (October 1971), pp 17-25. Transport costs are generally related linearly to distance. Long-distance rail rates for bark mulch from Oregon to Los Angeles were 1.2 to 1.6 cents per ton-mile. Truck haul rates for pulp chips and hogged fuel were about 3 to 4 cents per ton-mile for haul distances of 50 to 100 miles.

IEA Biomass Information Service, Current Awareness Bulletin (Institute for Industrial Research and Standards [IIRS], Dublin, Ireland, November 1977), 111 pp. A bibliography concerning: (1) animal wastes, (2) crop residues, (3) domestic urban wastes, (4) forestry products.

IEA Biomass Information Services, Current Awareness Bulletin (IIRS, Dublin, Ireland, February 1979), 122 pp. Abstracts of nearly 350 reports concerning all types of biomass and its conversion, including animal wastes,

crop residues, domestic-urban wastes, foresty products, and general and review topics.

Ince, P. J., How to Estimate Recoverable Heat Energy in Wood or Bark Fuels, General Technical Report FPL-29 (USDA Forest Service, Forest Products Laboratory, Madison, WI, 1979), 9 pp. Provides information and formulas which can be used to derive estimates of recoverable heat energy in wood or bark fuels in typical furnace and boiler or hot air combustion heat recovery systems.

Increased Energy for Biomass: 1985 Possibilities and Problems (Pacific Northwest Bioconversion Workshop, sponsored by Region X, U.S. Department of Energy, U.S. Forest Service, and Oregon State University's Office of Energy Research and Development, 1978), 204 pp. The purpose of this conference was to identify economic and regulatory barriers which currently restrict biomass use for energy. The program examined agricultural and peat applications and emphasized wood residue utilization.

Inman, R. E., Silvicultural Biomass Farms, Vol 1, Technical Report 7347 (Mitre Corporation, May 1977), 62 pp. Summarized the results of a six-volume report detailing the potential of wood grown as a fuel source on short rotation, densely spaced, "silvicultural biomass" farms.

Inman, R. E., D. J. Salo, and B. J. McGurk, Site-Specific Production Studies and Cost Analyses, Vol IV of Silvicultural Biomass Farms, Technical Report No. 7347 (Mitre Corporation, May 1977), 186 pp. The costs of producing silvicultural biomass on short-rotation, intensively managed farms at 10 study sites are estimated. A computerized economic model derives the cost estimates. The model identifies the sequence of operations for the farm and the materials and labor required. Site-specific characteristics are reflected in the cost estimates.

Intergroup Consulting Economists, Ltd., Economic Pre-Feasibility Study: Large-Scale Methanol Fuel Production From Surplus Canadian Forest Biomass, Part I (September 1976), 83 pp. Summarizes the findings of a study identifying technologies for large-scale gasification of roundwood to yield methanol -- i.e., plants ranging from 50 to 200 million gal/yr. Also relates findings on plant capital and equipment costs, product demand analysis, financial analysis and appraisal, and other economic impacts.

Intergroup Consulting Economists, Ltd., Economic Pre-Feasibility Study: Large-Scale Methanol Fuel Production From Surplus Canadian Forest Biomass, Part 2 Working Papers (Policy and Program Development Directorate, September 1976), 249 pp. The research presented investigates the practicality of using fiber-derived methanol as a substitute for hydrocarbons. The article presents: (1) specifications for the physical plant and its operations, (2) estimates of plant capital and equipment costs, (3) product demand analysis, and (4) financial analysis and appraisal.

Intergroup Consulting Economists, Ltd., Liquid Fuels from Renewable Resources: Feasibility Study (May 1978), 137 pp. Concludes that wood-derived liquid fuel is a major renewable resource which should be developed in Canada. This conclusion is based on an analysis of the full range of potential production processes and liquid fuel markets available for Canadian renewable resources.

Jamison, R. L., "The Forest as a Potential Source of Fuel for Energy," from Proceedings: Society of American Foresters (1977), pp 53-56. Contends recovery and use of forest residuals need much work before forest biomass can be used fully. Significant energy production from residuals is limited due to the small amounts economically available from the forest.

Johnson, F. L. and P. G. Risser, "Biomass Annual Net Primary Production and Dynamics of Six Mineral Elements in a Post Oak Blackjack Oak Forest," Ecology, Vol 55, No. 6 (Autumn 1974), pp [illegible] 1258. Uses dimension analysis to determine biomass and annual net primary production in a representative Oklahoma upland forest stand. To calculate the mineral budgets and annual cycle of N, P, K, Ca, Mg, and Mn in the forest, plant tissue concentrations were combined with biomass and production estimates.

Johnson, J. A., W. A. Hillstrom, E. S. Miyata, and S. G. Shetron, "Strip Selection Method of Mechanized Thinning in Northern Hardwood Pole Stands," The Northern Logger, Vol 28, No. 11 (May 1980), pp 26-27, 58-60. Four mechanized thinning methods are evaluated for economics and silvicultural implications. Strip-with-selection thinning proved to be both efficient and productive, although damage to the remaining stand exceeded expectations.

Johnson, R. C., "Some Aspects of Wood Waste Preparation for Use as a Fuel," TAPPI, Vol 58, No. 7 (July 1975), pp 102-106. Examples of different fuel preparation systems and their uses are considered. Effect of moisture on heat value is the main topic of discussion.

Jorgensen, J. R., C. G. Wells, and L. J. Metz, "The Nutrient Cycle: Key to Continuous Forest Production," Journal of Forestry (1975), pp 400-403. Studies a 16-year-old loblolly pine stand in the Piedmont of North Carolina to assess the distribution of nutrients in the soil and aboveground portions of the ecosystem. Nutrient accumulation rates and transfer within the ecosystem are also reported. Harvesting the aerial portion and larger roots of trees removes 12 percent of the total N, 8 percent of the extractable P, and 31 percent of the extractable K.

Junge, D. C., The Combustion Characteristics of Red Alder Bark, Report No. RLO-2227-T22-10 (Oregon State University, December 1978), 192 pp. Provides data on the combustion of red alder bark: optimum mass mean size of ash particles ranges from 0.06 mm to 0.43 mm, combustion air temperature has the greatest effect on thermal efficiency, and noncombustible ash from the fuel is relatively high (3.1 percent of total dry weight of fuel).

Junge, D. C., The Combustion Characteristics of Red Alder Sawdust, Report No. RLO-2227-T22-7 (Oregon State University, December 1978), 97 pp. Provides

data on firing red alder sawdust in an industrial spreader-stoker boiler: mass mean size of ash ranges from 0.62 to 1.05 mm (under optimum conditions), combustible content of boiler emissions ranges from 73.4 percent to 80.4 percent (under optimum conditions).

Karschesy, J. and P. Koch, Energy Production From Hardwoods Growing on Southern Pine Sites, General Technical Report 50-24 (USDA, Southern Forest Experiment Station, New Orleans, LA, 1979), 59 pp. After briefly describing tree species that are likely to be found growing on Southern pine sites, this document details alternative combustion technologies. Direct combustion, gasification, charcoal manufacture, and liquefaction are described in detail.

Keays, J. L., "Complete-Tree Utilization of Mature Trees," American Institute of Chemical Engineers, Vol 70, No. 139 (1974), pp 67-76. The biomass, pulp yield and quality, and processing problems for each tree component are discussed. Component biomass figures are given as average values for any temperate climate.

Kennel, R. P., C. W. Vail, and J. R. Bauer, Wood Energy Resources on the Delmarva Peninsula (Ultrasystems, Inc., January 1979), 88 pp. Determines the availability and reliability of wood supplies for use as fuels. After a detailed harvest cost analysis, the report concludes that the cost of fuels so produced is competitive with current prices of heating oil and coal.

Kimmins, J. P., J. de Catanzaro, and D. Binkley, Tabular Summary of Data from the Literature on the Biogeochemistry of Temperate Forest Ecosystems, ENFOR Project P-8 (Canadian Forestry Service, October 1979), 106 pp. Prepared as a reference source for evaluating the biogeochemical consequences of intensive forest biomass harvesting. The tables are intended to be a source of input data for a simulation model submitted by J. P. Kimmins and K. Scoullar (1979) to the Canadian Forestry Service.

Knight, J. A., "Pyrolysis of Pine Sawdusts," in Thermal Uses and Properties of Carbohydrates and Lignins (Academic Press, Inc., 1976), pp 159-173. An account of experiments on the pyrolysis of pine sawdust providing data on the yields and heating values of products, and on the compositions of noncondensible gases from 540° to 870°C.

Knight, J. A., D. R. Hurst, and L. W. Elston, "Wood Pyrolysis of Pine Bark Sawdust Mixture," in Fuels and Energy From Renewable Resources (Academic Press, 1977), pp 169-195. The physical and chemical characteristics of oils obtained from the pyrolysis of pine bark and sawdust are described.

Koch, P., Harvesting Energy Chips from Forest Residues -- Some Concepts for the Southern Pine Region, Technical Report SO-33 (USDA, Forest Service, Southern Forest Experiment Station, 1980), 24 pp. Reports on procedures for harvesting residual tops, branches, central root systems, brush, cull trees, and other fiber sources too small for economic harvest by conventional methods. About a dozen harvesting methods are described and illustrated. The cost of energy chips derived by these methods will likely range from $18 to $33 per green ton (1980).

Koch, P. and D. W. McKenzie, "Machine to Harvest Slash, Brush, and Thinnings for Fuel and Fiber -- A Concept," Journal of Forestry (December 1976), pp 809-812. Proposes the concept of a mobile hog which could either collect or distribute hogged slash. Such a system could recover 96,000 kg/ha (40 tons/acre, green weight basis) of harvestable material and residue. For sites deficient in organic matter, residual biomass could be hogged and returned to the forest floor.

Koch, P. and T. E. Savage, "Development of the Swathe-Felling Mobile Chipper," Journal of Forestry, Vol 78, No. 1 (January 1980), pp 17-20. Reports on the evolution of a self-contained harvesting machine to recover logging residues as chips for fuel or fiber. The 575-hp self-propelled chipper was field-tested on red alder stands in 1971; observations gathered during the tests are reported.

Krefting, L. W., "Use of Silvicultural Techniques for Improving Deer Habitat in the Lake States," Journal of Forestry, Vol 60, No. 1 (January 1962), pp 40-42. Discusses deer habitat requirements and various methods which provide suitable habitat. Concludes that techniques such as bulldozing and disking have some value for habitat improvement, but are cost prohibitive. The most effective method for improving habitat is the use of various timber cutting practices. The most beneficial cutting practice is that used for pulpwood production; short rotations result in a greater proportion of the stand's time spent as shrub growth, thereby producing more browse.

Leaf, A. L., ed., Impact of Intensive Harvesting on Forest Nutrient Cycling, Proceedings of Symposium (State University of New York, 1979), p 421. It is recognized that whole-tree harvesting increases the biomass yield per unit of land area, but the impact of the increased nutrient removal is less clear. The symposium papers provide a broad, critical analysis of this subject and identify areas which need more research.

Lemee, G., "Primary Productivity of the Forest," Ecologie Forestiere (1974), pp 135-153. Forest productivity calculated by measuring: (1) CO_2 exchange between the plant and atmosphere, (2) litter production, and (3) collected forest dry matter. A literature search produced worldwide values for primary production of various ecosystems.

Levi, M. P. and M. J. O'Grady, Decision Maker's Guide to Wood Fuel for Small Industrial Energy Users, SERI/TR-8234-1 (Solar Energy Research Institute, February 1980), 160 pp. Considers the technology and economics of various wood energy systems available to the small industrial and commercial energy user. No two situations are exactly alike; fuel amounts, types, costs, space availability, and capital vary from facility to facility. This book is intended to help a plant manager or engineer become more familiar with wood fuel systems so that informed decisions can be made about switching to wood for fuel.

Lieth, H. and R. H. Whitaker, editors, "Primary Productivity of the Biosphere," Ecological Studies, Vol 14 (Springer-Verlay, 1975), 339 pp. Synthesizes current knowledge of world primary biological productivity in

terms of methods of measurement, environmental determinants, the quantities of different communities and of the biosphere as a whole, the relationship to other biosphere characteristics, and the implications for man.

Lohrey, R. E., Growth of Longleaf Pine Plantations After Initial Thinning, SO-175 (USDA Forest Service, Southern Forest Experiment Station, 1974), 5 pp. Reports on the growth of planted longleaf pines for 5 years following thinning to various densities. Plantations were thinned at 24 and 25 years. Periodic volume growth after thinning increased with residual density. Relates diameter and volume growth of individual trees to stand density and initial dbh.

Lowery, D. P., Energy Required to Dry Wood, Research Note INT-172 (USDA Intermountain Forest and Range Experiment Station, July 1973), 5 pp. Two methods of drying commercial lumber are compared to determine which drying schedule is more efficient. Results indicate no difference between constant surface temperature drying (method one) and constant oven temperature (method two) in energy required.

Lowery, D. P. and T. R. Bohannan, Roundwood Product Potential in Logging Residue, INT-286 (USDA Forest Service, Intermountain Forest and Range Experiment Station, March 1980), 5 pp. An inventory on a clearcut area in a mixed Douglas Fir/Ponderosa Pine stand was performed to determine the quantity and quality of post-harvest residue. Roundwood products obtainable from this residue had an approximate value of $534,000 per acre. Products made from residue are generally of lower quality than those made from small trees.

Lowther, J. D., FLAME -- Forestry Lands Allocated for Managing Energy, Report No. TR-78-41 (Civil and Environmental Engineering Development Office, Tyndall AFB, September 1978), 27 pp. The study evaluates the feasibility of using wood growing on U.S. Air Force (USAF) installations to supply heat energy requirements. This was done by comparing energy requirements with wood resources and by studying the comparative fuel costs.

Mace, A. C., T. Williams, and J. C. Trappeiner, "Effect of Winter Harvesting Methods on Soil Bulk Density and Infiltration Rates," Minnesota Forestry Research Notes, No. 228 (University of Minnesota, June 15, 1971), 4 pp. In June 1970, bulk density and infiltration measurements were made at seven study sites on the Cut-Foot Experimental Forest, Itasca County, MN. Study sites composed of jack and red pine stands were harvested during the previous winter using full-tree and tree-length harvesting systems. Results show that the infiltration rates of sites harvesting during winter operations are similar in magnitude to those obtained for summer operations, but winter operations reduced heavy and medium disturbance sites by about 30 percent. Small differences in infiltration rates between full-tree and tree-length harvesting systems were observed.

Marshall, J. E., G. Petrick, and H. Chan, A Look at the Economic Feasibility of Converting Wood Into Liquid Fuel, Information Report E-X-25 (Canadian Forestry Service, Ottawa, 1975), 42 pp. Addresses the question of adequate fiber availability for conversion to liquid fuel and then analyzes the cost of such a conversion, concluding that given the current state of technology, alcohol probably cannot be produced at a competitive price.

Mattson, J. A., "Forest Residue Energy Potentials," from Proceedings of the Society of American Foresters, 1979 (October 1979), pp 307-315. This report assesses forestry energy potentials in four Forest Survey Units in Northern Wisconsin and Upper Michigan, and evaluates the energy situation for 10 of 20 mills in the region.

Mattson, J. A., R. A. Arola, and W. A. Hillstrom, "Recovering and Chipping Hardwood Cull Trees Having Heavy Limbs," in Symposium: Complete-Tree Utilization of Southern Pine, (1978), p 12. A system to reduce the bulk of large hardwood tops to facilitate skidding and chipping is described. A 21-acre field trial yielded 7.33 tons/acre at a recovery cost of $9.38/ton of green wood chips. Damage to the residual stand was not excessive.

Mattson, J. A., D. P. Bradley, and E. M. Carpenter, "Harvesting Forest Residues for Energy," Proceedings of Symposium on Fuels From Biomass, Vol 1 (Rensselaer Polytechnic Institute, 1978), pp 185-225. A case study of 18 million acres of commercial forest land in northern Wisconsin and Michigan shows that 40 million green tons of material should be harvested annually, about eight times the current harvest. Almost half of this amount is rough and rotten trees, tops, and limbs. The more significant portion is from improvement cuts such as thinnings, or from mature stands not harvested under current levels of demand.

Mattson, J. A. and E. M. Carpenter, "Logging Residue in Northern Hardwood Timber Sale," Northern Logger and Timber Processor, Vol 24, No. 7 (1975), pp 16,17,29. The volume and size of logging residue left after a timber sale in the northern hardwood forest type are reported. Twenty-eight percent of harvest residue was salvaged as pulp bolts.

McClure, J. P., N. D. Cost, and H. A. Knight, Multi-Resource Inventories - A New Concept for Forest Survey, SE-191 (USDA Forest Service, 1979), 68 pp. A brief historical review shows why Forest Service Renewable Resources Units are capable of multi-resource surveys. Also documents an approach to multi-resource inventories and reports on the status of a South Carolina pilot study.

McDermid, R. W. and J. R. Perkins, "Choker vs Grapple Skidders in Louisiana: A Production Cost Appraisal," Proceedings: American Society of Agricultural Engineers (Winter 1971). This study compares choker and grapple skidders to evaluate production volume and costs on several operations in Louisiana. Time-production studies were conducted for 24 days on each type of skidder.

Meeuwig, R. O., E. L. Miller, and J. D. Budy, Estimating Pinyon and Juniper Fuel and Biomass from Aerial Photographs, INT-274 (USDA Forest Service, Intermountain Forest and Range Experiment Station, November 1979), 9 pp. Describes techniques for using regression equations for estimating fuel loading, fuelwood volumes, and potential slash production using aerial photographs. The equations were developed for estimating the mass of various fuel components per unit crown area of single-leaf pinyon and Utah juniper.

Miles, Thomas R., Consulting Engineer, Report of Shelton Wood-Coal Firing Tests Conducted March 16 - April 2, 1980 (U.S. Department of Energy, Region X, May 9, 1980), 112 pp. Green wood residue and coal combinations were fired while boiler performance and gaseous and particulate emissions were measured. The study also describes the potential limitations to green wood firing at Shelton, and the possible implications for other boilers.

Miyata, E. S., Determining Fixed and Operating Costs of Logging Equipment, General Technical Report NC-55 (USDA Forest Service, North Central Forest Experiment Station, St. Paul, MN, 1980), 16 pp. Describes and analyzes all elements of equipment cost and gives a procedure for estimating fixed and operating costs.

National Association of State Universities and Land Grant Colleges, National Program of Agriculture Energy Research and Development -- The Current Situation -- The Plan -- Recommendations for the Future, Report No. ARPAC-76-1 (Report to the National Planning Committee of the Agriculture Policy Advisory Committee, September 1976), 89 pp. Studies agricultural energy research and development programs, with recommendations concerning future alternatives. A discussion of the role, objectives, and capabilities of the agricultural research system is included.

Nemeth, J. C., "Dry Matter Production in Young Loblolly and Slash Pine Plantations," Ecological Monographs, Vol 43, No. 1 (Winter 1973), pp 21-41. Presents the net productivity of the pine species and lesser vegetation plus turnover rates between the litter layer and soil organic matter in young pine plantations in the coastal plain area of North Carolina. Estimates of tree biomass and component production are based on equations derived from harvest data (15 slash pine and 41 loblolly pine trees).

Ohmann, L. F., D. F. Grigal, and R. B. Drander, Biomass Estimation for Five Shrubs From Northwestern Minnesota, FSRP-NC-133 (USDA Forest Service, North Central Forest Experiment Station, St. Paul, MN, November 1976), 17 pp. Biomass prediction equations estimate total aboveground biomass, leaf, stem, and current twig biomass of shrubs. The predictions are best for single plants but can be converted to apply to an area.

Paul, P. A., "Wood Chips for Fuel," Soil Conservation (September 1978), pp 16-17. Briefly examines the possibility of using wood fuel for energy production in New York's North Country.

Pecorano, J. M., R. Chase, P. Fairbank, and R. Meister, The Potential of Wood as an Energy Resource in New England (New England Federal Regional Council, Energy Resource Development Task Force Wood Utilization Group, September 1977), 100 pp. Promotes developing the use of wood energy in New England. General description of potential availability and use of wood energy for industry and the homeowner.

Pengelly, W. L., "Clearcutting: Detrimental Aspects for Wildlife Resources," Journal of Soil and Water Conservation (November to December 1972), pp 255-258. Addresses the contention that clearcutting forest stands is beneficial to wildlife due to increased forage availability. Holds that factors concerning other elements of the ecosystem are as important as food production, but have been ignored, e.g., increased snow accumulation on the forest floor (burying otherwise available forage), increased wind velocities, decreased ground moisture, and behavioral limits. Concludes that current oversimplification of forest ecosystems must be updated by increased basic research.

Pfister, R. D. and S. F. Arno, "Classifying Forest Habitat Types Based on Potential Climax Vegetation," Forest Science, Vol 26, No. 1 (March 1980), pp 52-70. Describes a method for classifying forest habitat types according to their potential climax vegetation. Quantitative data are obtained using simple time efficient procedures. The analysis considers a series of successive approximations utilizing synthesis tables, ordinations, environmental data correlations, and field testing of preliminary data.

Phillips, D. R., "Lumber and Residue Yields for Black Oak Saw Logs in Western North Carolina," Forest Products Journal, Vol 25, No. 1 (January 1975), pp 29-32. Presents regression equations to predict lumber and residue yields, sawlog weights, and lumber volumes. Equations are based on a sample of 40 black oak trees 12 to 16 in. dbh. These trees were felled and bucked into logs 8 to 16 ft in length with a minimum scaling diameter of 8 in. dib. The logs produced an average of 55 percent lumber, 20 percent chippable residue, 15 percent bark residue, and 10 percent sawdust.

Phillips, D. R., Total Tree Weights and Volumes for Understory Hardwoods, Vol 60, No. 6 (TAPPI, June 1977), pp 68-71. Understory hardwoods (below 5.0 in. dbh) from the mountains of North Carolina and piedmont of Georgia were sampled to develop regression equations to predict total tree green and dry weights and total tree volumes. Properties of eight of the more important species are compared, indicating the importance of site when determining understory tree weights.

Phillips, D. R. and J. R. Saucier, A Test of Prediction Equations for Estimating Hardwood Understory and Total Stand Biomass, Georgia Forest Research Paper (Georgia Forestry Commission, August 7, 1979), 8 pp. Reports the results of a study to field test in northern Georgia equations predicting weights of understory and overstory hardwoods. Understory tree weights were overestimated by 3.8 percent and overstory tree weights underestimated by 3.0 percent when compared with actual total green weight. On individual plots, prediction error ran as high as 11.7 percent for understory and 22.0 percent for overstory trees.

Phillips, D. R. and J. G. Schroeder, Predicted Lumber and Residue Yields from the Merchantable Stem of Shortleaf Pine, Research Paper SE-128 (USDA Forest Service, Southeastern Forest Experiment Station, May 1975), 12 pp. Fifty-seven trees from a mature stand and an old field stand in Mississippi were processed in a bandmill. Fifty-four percent of the merchantable stem became lumber, 26 percent chippable residue, 10 percent bark, and 10 percent sawdust. Regression equations were developed from these samples to predict lumber and residue yields. Stem weights and stem cubic volumes are also predicted.

Pickford, S. G. and J. W. Hazard, "Simulation Studies on Line Intersect Sampling of Forest Residue," Forest Science, Vol 24, No. 4 (December 1978), pp 469-483. The reliability of the line-intersect sampling method in estimating residue volumes was tested. Results show that this method requires considerable effort, but high levels of precision are obtainable.

Pingrey, D. W. and N. E. Waggoner, Wood Fuel Fired Electric Power Generating Plants, Summary Report, Vol 1, TID-28963 (NorWest-Pacific Corporation, Seattle, 1979), 20 pp. Presents the results of a questionnaire sent to pulp and paper and other industries who burn wood for fuel to produce steam-generated electricity. Information obtained indicated: (1) of the 39 pulp and paper mills reporting, only five were not co-generating, and (2) all mills used their wood wastes, and about one-half of the mills purchased waste wood residue.

Poo Chow, "Wood as Fuel -- Forest Can Be Utilized More Fully as an Energy Source," Illinois Research, Vol 19, No. 2 (Spring 1977), pp 6,7. A brief look at wood fuel characteristics, including charcoal and its advantages as a fuel.

Post, L. R., "Dry Matter Production of Mountain Maple and Balsam Fir in Northwestern New Brunswick," Ecology, Vol 51, No. 3 (Late Spring 1970), pp 548-550. Dry matter production of even-aged stands was measured to determine annual weight increment. Component increment per unit area data is presented.

Potential Sites for Joint Venture Biomass Fueled Power Plants, FESA-TS-2078 (prepared by Ultrasystems, Inc., for the U.S. Army Facilities Engineering Support Agency, Technology Support Division, 2 January 1980) 151 pp. About 170 Army bases were evaluated for their heating and electrical needs versus fuel availability from on-base forests. Potential partnership arrangements between the Army and local utilities were identified.

Ratcliff, P., "Wood Disposal or Wood Harvesting" (International Shade Tree Conference, Detroit, MI, August 1975), p 2. A short description of Morbark's whole tree chipper and its use to an urban forester.

Reed, T. B., "Synthetic Fuels From the Forest," Forest Notes, 128 (Society for the Protection of New Hampshire Forest, 1977), pp 22-24. Presents methods for distilling wood fiber to obtain fuels (methanol, etc.); included are descriptions of commercial units, their capacities, and efficiencies.

Report on the Review of the DOD Forestry Program, No. 80-805 (Defense Audit Service, Systems and Logistics Audits Division, April 2, 1980), 12 pp. Contains the summary and recommendations from a review of the Department of Defense (DOD) forestry program. Evaluates the management of timber resources to see if the program conforms to the most efficient and accepted forestry practices.

Resler, R. A., "Clear-cutting: Beneficial Aspects for Wildlife Resources," Journal of Soil and Water Conservation (November to December 1972), pp 250-254. Discusses and reviews literature addressing the issue of clear-cut logging practices and their influence on forest wildlife. Holds that clearcutting provides a more diverse habitat because it opens up the forest canopy, which allows a greater insulation of ground vegetation. This, in turn, encourages the growth of those herbaceous species most utilized as food by wildlife. However, concludes these benefits will only be realized through careful planning and execution.

Ribe, J. H., Puckerbush Weight Tables, Miscellaneous Report 152 (Life, Sciences and Agriculture Experiment Station, University of Maine at Orono, December 1973), 92 pp. To develop a dimensional regression analysis technique, data had to be gathered on 11 puckerbush species using destructive sampling of 30 trees of each species; the tables are based on these data. Regression equations were developed for each component (leaves, branches, stem, and total) and tables prepared using these equations.

Roop, R. D., Energy From Biomass: An Overview of Environmental Aspects (Environmental Science Division, Oak Ridge National Laboratory, 1978), 15 pp. This paper reviews recent literature regarding energy-from-biomass to identify environmental issues and suggest needed research in this area. There is a heavy emphasis of harvest and removal impacts.

Rose, D. W. and D. S. DeBell, "Economic Assessment of Intensive Culture of Short Rotation Hardwood Crops," Journal of Forestry, Vol 76, No. 11 (November 1978), pp 707-711. Hardwood crops coppiced on 4- and 10-year cycles at spacings of 4 x 4 feet,, and 12 x 12 feet,respectively, appear economically feasible. Results relating the economic analyses of the intensive culture alternatives are presented.

Royal College of Forestry, Project Whole Tree Utilization -- Final Summary (The Royal College of Forestry, Garpenberg, Sweden, 1977), 21 pp. At a foreseen gross removal of 62 million m^3 solid merchantable wood, 30 million m^3 of wood fiber is left in the forest. About 7 million m^3 of this can be harvested as stumpwood. Methods for such use are summarized, as are possible impacts on the forest environment.

Russell, B., The Feasibility of Generating Steam in West Alabama Using Wood as a Fuel--Tuscaloosa Veterans Administration Hospital, Report No. ARC-76-125-4495 (Energy Conservation Company, September 1976), 75 pp. Covers wood and wood waste procurement, qualitative and quantitative economic analysis of wood as fuel, and equipment recommendations and economic

analysis. Findings show that wood is a clean, renewable, economical candidate for fuel. A contractual price for the actual delivery of wood fuel is uncertain, but will likely remain lower than the cost of fossil fuels for at least 10 years.

Salo, D. J., R. E. Inman, B. J. McGurk, and J. Verhoeff, Silvicultural Biomass Farms, Volume III, Technical Report No. 7347, Vol III (Mitre Corporation, May 1977), 223 pp. Screens land potentially available for silvicultural biomass farms using geophysical suitability criteria. The annual potential production of energy from biomass is estimated on a regional basis. Ten hypothetical biomass farm sites are described.

Sampson, G. R., H. E. Worth, and D. M. Donnelly, Demonstration Test of Inwoods Pulp Chip Production in the Four Corners Region, Research Paper RM-125 (USDA Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO, July 1974), 19 pp. The demonstration described in this paper illustrates the many factors involved with in-woods wood chip production. Costs for each separate operation (i.e., skidding, chipping, etc.), downtime and its causes, and chip yield are included in the data.

Sarkanen, K. V., "Renewable Resources for the Production of Fuels and Chemicals," Science, Vol 191 (February 20, 1976), pp 773-776. Cites the abundance of all renewable resources including wood. Conversion methods for producing chemicals and/or energy are also briefly discussed.

Schier, G. A., Rooting Stem Cuttings from Aspen Seedlings, INT-282 (USDA Forest Service, Intermountain Forest and Range Experiment Station, February 1980), 4 pp. Spring shoots and shoots induced to develop by defoliation were studied to obtain rooted seedlings from stem cuttings. Only cuttings from spring shoots treated with a commercial rooting powder rooted. There were significant differences in rooting ability among seedlings (genotypes).

Schneider, M. H., "Energy From Forest Biomass," The Forestry Chronicle (August 1977), pp 215-218. Reviews some basic wood fuel characteristics and various conversion routes.

Schnell, R. L., "Whole Tree Chipping in the Tennessee Valley." Southern Lumberman (September 1, 1978), pp 13-15. Describes equipment, manpower, cost, and methods for whole-tree chipping in the Tennessee Valley.

Schooley, F. A., S. J. Mara, D. A. Merdel, P. C. Meagher, and E. C. So, Water and Land Availability for Energy Farming, SRI International Project No. 7877 (prepared for U.S. Department of Energy, Division of Distributed Solar Technology, Biomass Energy Systems Branch, 1979), 22 pp. To assist the Department of Energy in determining the physical and economic availability of land and water resources for energy farming. The study identifies the Southeast as a favorable area while the Northwest and North-Central states should also be considered.

Scola, R., Wood -- The Renewable Fuel, Technical Report ARLCD-TR-78051 (Army Armament Research and Development Command, Large Caliber Weapon Systems Laboratory, February 1979), 28 pp. Briefly explains why wood once again is being considered a prime fuel resource.

Seaman, J. F., "Energy and Materials From the Forest Biomass," presented at the Symposium on Clean Fuels From Biomass Wastes (Orlando, FL, January 25-28, 1977), pp 153-167. This paper suggests priorities and strategies allowing forest biomass to contribute as much as possible to the United States' materials and energy budget. An economic assessment of available technology to extract chemicals from timber surpluses shows high capital costs and profits too low for the risks involved.

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fuel-value analysis of wood, considers the methods best suited for using that fuel, and finally discusses the resources available for increasing wood resources and use. In all situations, the author compares wood to coal, oil, and other fuels.

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Zerbe, J., "Sources of Energy Production," Conference on Capturing the Sun Through Bio-Conversion (1976), pp 145-152. Describes possible sources of fiber residue on a nationwide basis (millwastes, etc.) and the diversity of end products derivable from the waste (e.g., chemicals, energy, etc.).

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APPENDIX B:

CALCULATION METHOD FOR ESTIMATING AVAILABLE HEAT ENERGY

The theoretical maximum heat released during the combustion of oven-dry wood is about 9200 Btu/lb (21 391.20 kJ/kg) in a closed system. Eight percent moisture content (MC) (wet basis) cannot be removed by drying; this is termed "bound water" and during combustion the heat required to vaporize this "bound water" is lost up the flue. The higher heating value (HHV) adjusts for this loss, giving 8500 Btu/lb (19 771 kJ/kg) as usable heat energy content.

$$\text{HHV} = 9200\ \text{Btu/lb}\ (21\ 399.1\ \text{kJ/kg}) \times (1\text{-MC})$$

Oven-dry wood is not always available for combustion, so under normal operating conditions there are usually higher moisture contents. Each pound of water in the wood requires 1000 Btu (1055 kJ) for vaporization. The lower heating value (LHV) relates the amount of usable heat content after removals due to the moisture content.

$$\text{LHV} = 9200\ \text{Btu/lb}\ (21\ 399\ \text{kJ/kg}) \times (1\text{-MC}) - 1000\ \text{Btu/lb}\ (1055\ \text{kJ/kg})\ (\text{MC})$$

GLOSSARY

air dry: 15 to 20 percent moisture content (wet basis).

annual growth increment: Net amount of mass gained per unit area due to plant growth in 1 year's time.

biomass: Total mass of material of biologic origin (in this report refers mainly to trees and shrubs; also called "standing biomass").

board foot: A unit measurement of lumber, representing the cubic volume equivalent of a board 1 ft long, 12 in. wide, and 1 in. thick.

bole: The main stem of a tree.

buck: Removal of the top waste portion of a conifer bole or hardwood branch at a minimum diameter value (for sawtimber 6 in. [152.4 mm] minimum, 3 in. [76.2 mm] diameter for pulp); bucked material consists of tree forks, small diameter stems and branches, and foliage.

conifer: See softwoods.

coppice: Ability to sprout from a stump, each sprout capable of becoming a trunk.

crown: The branches and foliage from the upper portion of a tree.

clear cut: The harvest of all commercially valuable trees from an area at one time.

commercial harvest: Here used to mean harvest of trees for uses such as pulpwood and sawtimber.

cull: Inferior quality trees which are not harvested during logging because they are the wrong species, undesirable geometrically (rough), diseased (rotten), or too small to be used commercially.

dbh: Diameter at breast height (4.5 ft [1.4 m]).

dib: Diameter inside the bark.

deciduous: See hardwood.

excurrent growth: Dominant growth of main trunk extending to the top of the crown -- e.g., spruce, pine.

hardwood: Broad-leaved flowering trees; most are capable of coppice production.

International Rule: Board foot measurement, standard scale of U.S. Forest Service.

landing: Cleared location in the woods where felled trees are collected to be sorted, cut up, and loaded for transport.

mast: Nuts accumulated on the forest floor serving as food for wildlife.

moisture content: Amount of water represented as the percentage of a tree's dry weight or wet weight (green weight).

merchantable timber: Trees having no serious defects in quality limiting present or future commercial use for lumber products.

residue: Wood remaining in the forest as waste after conventional logging; e.g., limbs, tops (similar to forestry term "slash").

rotten: Diseased or dead tree unsuitable for commercial use.

rough: Live tree which, due to its geometry, does not not contain at least one 12-ft (3.7-m) saw-log, or two noncontiguous saw-logs each 8 ft (2.4 m) or longer.

silviculture: The development and care of forests.

softwoods: Botanical group of coniferous trees that bear cones, have needles or scale-like leaves, usually evergreen. Does not refer to the actual hardness of the wood.

skid: Towing a felled tree to a specific area for further processing, usually done with mechanical systems.

stand: Group of trees sufficiently uniform in terms of age, species, and condition to be distinguishable from the rest of the forest.

stumpage: Fee paid for the right to harvest standing timber.

suppressed: Trees stunted in size due to poor growth conditions.

sustainable yield: Amount of wood that can be removed from the forest without exceeding net annual production.

topwood: see crown.

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Kingsport, TN 37662

Indiana Army Ammunition Plant
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Charlestown, IN 47111

Iowa Army Ammunition Plant
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Middletown, IA 52638

Kansas Army Ammunition Plant
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Parsons, KS 67357

Milan Army Ammunition Plant
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Sharpe Army Depot
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Lathrop, CA 95331

Sierra Army Depot
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Tobyhanna, PA 18466

Rocky Mountain Arsenal
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Commerce City, CO 80022

Lake City Army Ammunition Plant
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Independence, MO 64056

Volunteer Army Ammunition Plant
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Chattanooga, TN 34701

Watervliet Arsenal
ATTN: SARWV-FEE
Watervliet, NY 12189

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Pine Bluff, AR 71611

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Louisiana Army Ammunition Plant
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Arlington, VA 22212

Environmental Protection Agency (EPA)
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WASH DC 20460

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Battle Creek, MI 49016

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